SeeSaw: a hybrid synthesizer balancing between analog motion and a digital sound

Master Thesis

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Sound and Music Computing

Document created with Overleaf. The printed circuit board has been developed with Ki-CAD and the audio core has been programmed with Max/Gen $\sim$.

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Abstract:

SeeSaw presents and discusses methods for implementing a hybrid synthesizer, by employing a digital embedded platform for editing digital signal processing algorithms in realtime. The aim of the project is the development of multiple instrument patches using synthesis techniques and methods in Max/gen visual programming language. Analog circuits are developed as supplementary modulation effects for enhancing the digital audio core. Moreover, the project investigates the impact of electro-mechanical parts both from sound aspects and design interface perspective. The majority of the digital synthesizers are based on simple knob/button interfaces that lack intuition and expressive quality. In return, this research aims to address these challenges by proposing a new hybrid digital interface, designed and reinforced by analog circuits and mechanisms, that allows for syn-aesthetic human-machine interactions.

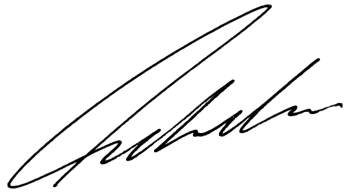
Contents

Preface

This Master thesis is part of my personal journey on music effects and synthesizers which has started back in 2009. The current project is the continuation of my Bachelor's Thesis project which explored the domain of electronic sound and proposed a new analog synthesizer interface for generating and manipulating audio signals[31]. Nevertheless, my Sound and Music Computing journey just begun by merging the boundaries between the digital and the analog domain. A very astonishing moment for me was when I came across on a Youtube's video where Alessandro Cortini and Don Buchla were performing together in the stage the masterpiece "Everything Ends Here"[8]. The power of the Buchla synth modules inspired me a lot, so I decided to develop my next synth. The SeeSaw is my proposal of an integration of a holistic design, an analog system with digital audio core which can be an open source and a re-programmable device.

I want to thanks from the deep of my heart my supervisor Dan Overholt for his endless support on this journey and Valia Fragkia for her patience and her impeccable design skills.

Aalborg University, October 7, 2022



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Chapter 1

Introduction

The presented research is focused on the design of a hybrid desktop synthesizer instrument. Synthesizers belongs to a diverse family of musical instrument interfaces which generate audible periodic signals who's frequency and functions can be controlled by the user by tweaking knobs and by using a music controller such as a MIDI interface is[13]. Synthesizers are widely used from independent live performance artist and music production studios as they tend to color a soundtrack with futuristic sonic nuances. It is not just a coincidence that Giorgio Moroder (composer, songwriter, and record producer) said that he was looking for the "Sound of the future" thus he used a synthesizer[20]. These musical instruments can differentiate from each other depending on the technical specifications and the different synthesis techniques which their circuits are based on. More specifically, the research focuses on a desktop semi modular synthesizer which is a sophisticated compact design and it can provide surprisingly many different sonic nuances and melodies, compared always to their small footprint. A semi modular synthesizer has internally a pre-wired basic arrangement of the signal flow, in fact the most popular reason in using a semi modular synthesizer is that the user can use patch cables and override some of the internal connections. Nowadays, the most important characteristic in a semi-modular synthesizer is not just the technology which is used behind the front panels but it is the design of the interface. Is the ability to control the sound modules with control voltages through a intuitive, dynamic and flexible interface.

1.1 Problem Statement

Commercial synthesizers appeared to have a prevalent interface design where the user needs to perform a music piece by tweaking knobs and by pressing hardware buttons. The majority of the desktop portable synthesizers need a MIDI controller in order to produce a melodic music sequence, and it is often that a MIDI controller is more intuitive in controlling the synthesizer than the actual instrument's interface. In addition, hybrid synthesizers and digital musical interfaces encapsulate secondary functions under the hood, which are hard for the musicians/users to remember them by heart, so the device's manual instructions needs to be next to the synth in order to recall the functions and get more familiar with the button combinations. If the complexity of a desktop synthesizer is increased, the steeper learning curvature for the user to learn how to perform through its interface. From the other hand, analog desktop synthesizers are much simpler to use them in a performance, in fact they lack the sound flexibility of a digital instrument. The golden ratio is somewhere between the two technologies. Analog synthesizers require complex circuits to achieve rich in harmonics and time variant sounds but from the other hand if a digital synthesizer is bad implemented, without evaluating the user's intuition, then it can be hard to be played or just boring.

1.2 Research Question

The question is how a musical interface design affects the music performance and how it can improve the syn-aesthetic human-machine interactions.This research aims to address these musical performance challenges by proposing an intuitive hybrid synthesizer interface which enhances artistic interpretation and exploration and allow the user to perform in a more creative and gestural way. At the same time, the challenge is the design of a digital core which sound is enhanced by analog synthesis techniques for retaining the original perceptual feeling of performing through an analog instrument's interface.

1.3 Target Group

The target group of SeeSaw synthesizer are people who are anyhow engaged with music technology and arts and who would like to perform experimental electronic music and electric soundscapes. People who need a portable device and an instrument that can be performed easily. Semi modular synthesizer users might find SeeSaw an alternative option as it offers a lot of features in a small package and there are a lot of patches which ca be connected in external devices such as drum machines and synthesizers. At the same time the audience for this device can be music artists who they would like to take a step further and experiment with their own sounds by programming the digital core of SeeSaw which can be open to everyone.

Chapter 2

Background Research

In this chapter, the historical background research and iconic Robert's Moog and Donald Buchla's designs will be presented. Relevant, academic research on the topic of synthesizer sound will be presented and discussed. Finally, the most relevant present devices will be discussed based on the user's interaction design. Additionally, inspiring synthesizer designs from the music industry will be analyzed and evaluated towards both their design and performance aspects.

2.1 Background

There are two dominant synthesizer approaches until today, which have been both developed in the decade of 1960 in United States of America. The first approach is used by the pioneer Robert Moog and it is based on subtractive synthesis[23]. In this synthesis technique a rich in harmonics sound is generated by an oscillator, then the sound is fed in a filter section which removes or subtracts harmonic contain from this rich sound. Subtractive synthesis is all about morphing the sound by filtering out a particular frequency range[19]. This synthesis technique is quite similar to the human voice biological mechanism. Robert Moog's synthesis approach was already known, however he combined existing ideas and he turned them into a new modular prototype instrument, called "the Abominatron". Moog's synthesis technique is known today as the East Coast approach.

Similarly, on 1965 in the west coast, a pioneer named Don Buchla designed a new instrument which was called "Buchla 100 series". Buchla believed that each of the devices he designed was a unique instrument, thus he wouldn't call them synthesizers[5]. The fundamental of Buchla's synthesis approach was exactly the opposite from Moog's. The technique approach is called additive synthesis[24]. This synthesis technique combines sinusoid signals together which have different frequency and amplitude range. The sum of these signals is a new constructed complex waveform. Buchla used waveshaper circuits to alter the sound source's

Figure 2.1: Prototype Moog Modules [12]

waveform and provide a harmonically rich contain to the existed sound as well. Instead of using a filter section which cuts out frequencies, Buchla was able to use his technique to morph the sound. The technique is also called West Coast synthesis.

2.2 Related Historical Designs

Buchla Electronic Musical Instruments introduced back in 1972 the Music Easel[2]. It was a considerable small, portable and semi modular synthesizer build in a travel suitcase, featuring two complex oscillators, waveshaper a sequencer and a copper based touch sensitive keyboard. The Music Easel was a performance instrument which could be carried easily compare to the huge modular synthesizer setups. Furthermore, the Music Easel revolved around the idea of re-program the instrument. There were an expansion port in the interface panel where the user could plug in an auxiliary card and create additional presets and sounds. This interface offered a very intuitive way of music expression and production

At that time synthesizers could be played with an electronic keyboard. The music intervals and the design was borrowed from the classical piano. Electronic Music Laboratories release in 1970 the ElectroComp EML-100 and according to the books Patch & Tweak[5] this particular synthesizer unit is most probably the very first portable semi modular with a two voice keyboard, which means that the keyboard was capable to send at the same time two different control voltages with the press of two keys. While the design interface of a traditional frequency tracking synthesizer with a piano style keyboard predetermined a discrete set of gestural performances, the case of Buchla Model 113 Touch Controlled Voltage Source is an inspiring reference for the current project. The fundamental of this touch interface is based on resistance touchplates where two different copper segments are connected while the skin resistance acts as a bridge between the copper

Figure 2.2: Music Easel

segments. According to Modular Electronic Music Systems Don Buchla invented this touchplates on the time he was working for NASA. The touchplates were used as sensors inside the rocket fuel tanks[29]. Don Buchla design is considered iconic especially when it comes to his musical control interfaces as he set a new boundary for intuitive interaction in musical performance.

2.3 Related Academic Research

Sean Luke from the department of Computer Science George Mason University published the Computational Music Synthesis book[17] which describes how to synthesize digital music in software. The contribution to this research is found in the detailed explanation of synthesis techniques such as the additive and the subtractive synthesis followed by a lot of examples of historical background and how the computational synthesizer music has been developed during the times.

One of the most iconic Buchla sonic nuances are based on the Low Pass Gate and to the waveshaper section. In 2013 Julian Parker's and Stefano D'Angelo published the paper "A Digital Model Of The Buchla Lowpass-Gate"[25] in Digital Audio Effects conference or or DAFX '13. Their research suggest a computationally light model of Buchla's Low Pass Gate section. The digital model has been created in MAX/MSP Gen$\sim$ and it emulates the physical behaviour of the optocoupler component and the analog electronics components electrical analysis of

Figure 2.3: Detail of the 113 Touch Controlled Voltage Source touchplate, David Tudor Collection 09/23/2019

the filter/gate. The results of this research provide sonic similarities between the analog electronics sound and the digital implementation.

In addition, the book Patch and Tweak by Kim Bjørn and Chris Meyer which explores modular synthesis through simple explanations[5] of the fundamental theories of synthesizers has been a great inspiration for this project. The book presents all of the commercial musical interfaces eurorack interfaces classified according to the type of the sound module. Moreover, interviews with the most inspired musicians of electronic music synthesis and manufacturers are presented, such as Hans Zimmer, Suzanne Ciani but also Make Noise and Verbos Electronics founders.

In addition, Suzanne's Ciani "Composer Grant" has been a very helpful document explaining the composition connections between the modules of Buchla's connections on a series 200 instrument[7]. Suzanne Ciani is also providing block diagram and their impact on the composed sound.

Finally, this project wouldn't be real without Electrosmith and Graham Wakefield continuous research and his most recent development of the Oopsy patch which is the bridge between the programming language and the microcontroller used in this project[32]. The paper called "A streamlined workflow from Max/gen$\sim$ to modular hardware" which was published in NIME conference in 2021, has contributed to the implementation of the fundamental components of the hardware design. At the same time SeeSaw research goes on, Cycling 74' announced on 3rd of October 2022 Graham's Wakefield and Gregory Taylor the first Max/gen$\sim$ book"Generating Sound and Organizing Time: thinking with gen$\sim$ Book 1"[33] which will be published early November 2022. The content will be very helpful for reinforce the future of the current research question and development.

2.4 Relevant Musical Interfaces

Current developments on the Musical Interfaces borrows characteristics from both East and West Coast approaches. The project will be navigated through haptic Digital and Hybrid Musical Interfaces as the key point is the real time musical performance with the use of a hardware device. Thus, the research is oriented in understanding the design principles, both from sound perspective but also from the interaction aspects. Therefore, some different type of synthesizer units will be briefly analyzed below.

2.4.1 Critter and Guitari Organelle

Organelle is a tactilated Digital Musical Interface for sound generation. This electronic instrument system integrates an ARM Cortex microprocessor, a RAM memory which run on Linux Operational System which make the unit a portable music computer. The audio core includes as many audio patches as the memory is held. The audio effects and synthesizers are programmed in a graphical patching program which is called PureData and it is an open source[6]. Furthermore, the audio algorithms can be control through an integrated piano style keyboard. Consequently, Organelle is an innovative idea not only because of its compact size and the natural feeling wooden keyboard controller but also, what makes the instrument unique is the user possibility to program in PureData new audio patches and flash them into the digital instrument. However, it is completely a digital instrument but it is nice that it can be programmed from the user.

Figure 2.4: Organelle by Critter & Guitari

2.4.2 Winterbloom

Winterbloom creates small eurorack modules which are really inspiring. The Castor and Pollux Voltage Control Oscillator is a two voice digital oscillator based on Juno synthesizer[11]. The SeeSaw draws inspiration from the two voice programmed sound engine and its features, such as the waveshaper and the oscillator stacking which is similar to Buchla's Complex oscillator. Also, the interface is quite innovative and useful for the current projects for two reasons. The interface is a printed circuit board which allows the quick fabrication of the illuminated surface elements such as the blinking LEDs which light through the pcb material. The second reason is that Winterbloom is an open source oriented company and their design files have helped the developer of SeeSaw to understand the techniques for designing the printed circuit board interface.

Figure 2.5: Winterbloom Oscillator for Eurorack

2.4.3 Make Noise 0 Control

0 Control is a control voltage controller with resistance touchplates instead of using hardware buttons. The Make Noise team supports Don Buchla design of the touchplates attributes and it encapsulates them in a very flexible device which is in a small size as well. SeeSaw draws inspiration from their devices and especially the way these machines are performed live. In contrast, with the Organelle this musical interface does not produce any sound by itself, however it is capable for producing sequenced voltage signals for controlling different synthesizer aspects which are base on Eurorack standards[5]. The Eurorack electrical specifications provides a typical voltage level of ±5V for audio and low frequency oscillators and 0-10V for control voltages. All of the devices, which follow the Eurorack standards, can safely communicate with voltage signals without any chance of damaging their circuits.

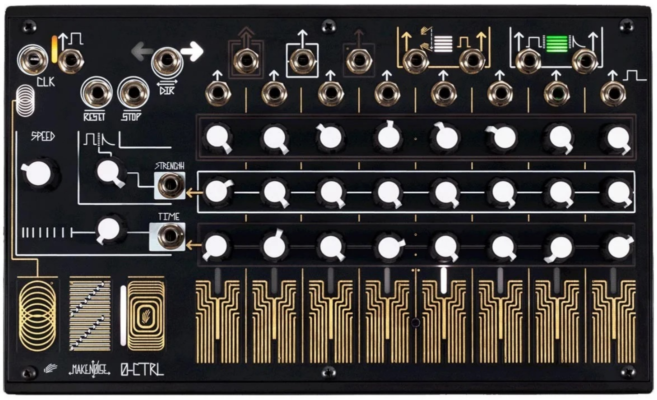


Figure 2.6: Make Noise 0-Control

2.4.4 Make Noise Strega

Strega has a very playful design which enhances the sonic character of the device. Strega is a collaboration between the electronic music artist Alessandro Cortini and Make Noise team[18]. It is an experimental sonic device since it unifies a delay section between the sound source and the filter section. In addition, the touchplates have a different function than the previous devices, as they have internally in the circuit, bridge connections which every time that two or more points are touched with bare fingers create random events. Thus, all of the unexpected and unclear soundscapes which can be occurred when randomness is introduced set this machine very intuitive and interactive, it somehow strengthen the user's machine interaction. SeeSaw draws inspiration from the aforementioned Strega synthesize techniques and tries to apply them in its design on its own way.

2.5 summary

The current project draws inspiration first of all from the digital musical instrument of Critter and Guitari due to the fact that the user has the freedom to re-program the sound engine in PureData. In addition, an intuitive user's interface will be implemented based on Don Buchla's designs taking into consideration the front panel design techniques of the latest Make Noise controllers. Moreover, the Strega experimental synthesizer incorporates a mix of West Coast experimental approaches in a small semi modular device which falls under the Eurorack specification. The outcome of the background designs will be analyzed and evaluated in this report.

Figure 2.7: Make Noise Strega

Chapter 3

Methodological Framework

The research objective is pursued through analytical and experimental methods. An analysis overview of the digital and analog electronics circuit has been made and the output values of the analog circuits have been calculated. The algorithm for the digital audio core has been developed in Max/gen$\sim$ visual programming language. In the meantime, the electronics design and the interface design have been made produced with KiCAD. Then, an electronic prototype were captured in the breadboard to adjust, tune and finalize the electronics design and validate the analytical values. The synthesis technique has been decided to be called experimental synthesis, as it is mainly inspired from techniques such as East Coast Synthesis, although the building block has been designed and implemented using these techniques but altered on an inspirational way. Also, SeeSaw tries to follow the trend of the musical era we are going through, which is strengthened and it gets inspired by music tools such as the Make Noise Strega. However, even if there might be similarities to the aforementioned technique and music instrument, SeeSaw encapsulates all of these elements on its own intuitive way.

3.1 Hybrid Experimental Synthesis

The synthesis technique consist of both analog and digital electronic circuits and elements. A briefly explanation of the notation used in this project for every block of the block diagram will be presented for your convenient. First, the audio sources functions which are all digitally implemented through the visual programming language MAX/MSP using the realtime extension patching environment Gen$\sim$, will be explained. This programming environment allows for compiling the visual objects into code. Secondly, the communication protocols which carry important information and signal between the different blocks will be presented. And finally, there will be figures and descriptions about the analog modulation circuits, which produce voltage signals to control and manipulate the audio signals.

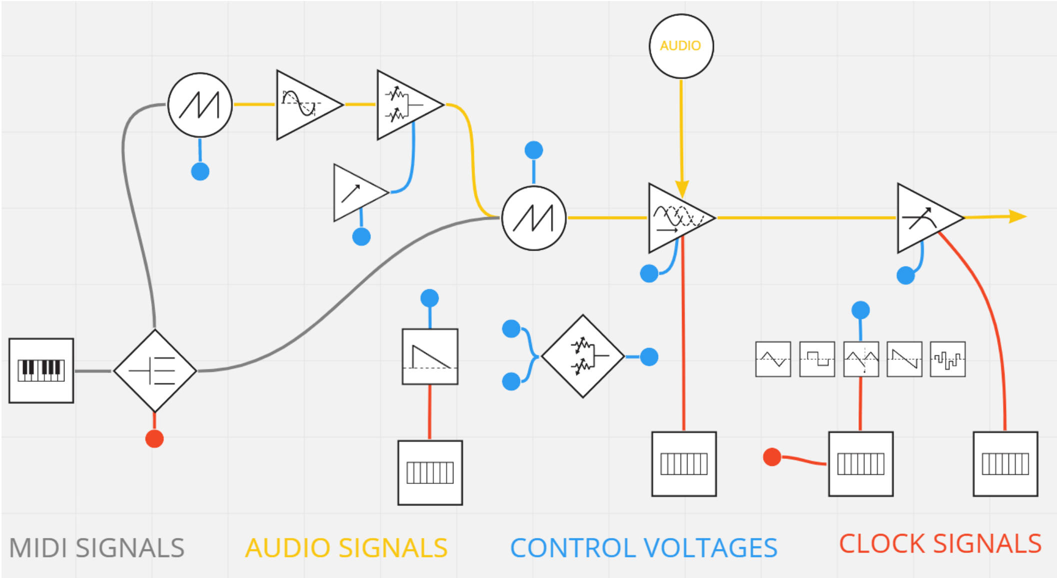


Figure 3.1: SeeSaw block diagram

3.1.1 Complex Oscillator

A complex oscillator is an audio engine which generates a constant tone. It is the most important section of a synthesizer as it produces periodic waveforms in its output stage. The usual waveforms are the triangular, sinusoidal, sawtooth and pulse. Of course, every single waveform has a different amount of odd and even harmonics which provide different timbre nuances. The oscillators frequency range is within the audible rate and in order to be a tool for performance is better to limited down from 27.5Hz to 7040KHz following the Buchla complex oscillator parameters. In SeeSaw system there will be two oscillators. The first oscillator is a complex oscillator and it modulates the frequency of the second oscillator. In fact, what makes these oscillators complex is that there is an attenuator between the two oscillators where an external modulation effect such as an envelope generator or a low frequency oscillator can modulate the depth of the final sound. Finally, a complex oscillator has a waveshaper configuration where in SeeSaw case it starts from a sinusoidal waveform and it is gradually transformed into sawtooth and triangle waveform shapes.

3.1.2 Delay

A delay unit will be used to create atmospheric sound patterns and to provide Karplus Strong[15] string instrument effects when it is set in fast delay period. The input signal is fed into the delay line where it is stored always accordingly to the samplerate. Practically, delay line is controlling the time between every repeat. Then, the damping controls the number of the repeats where a portion of the output of the delayed signal is routed back into the input and the delay gets quieter each time and eventually the sound dies out in decaying echoes. Last, the mix section controls the blend between the dry and the delayed signal.

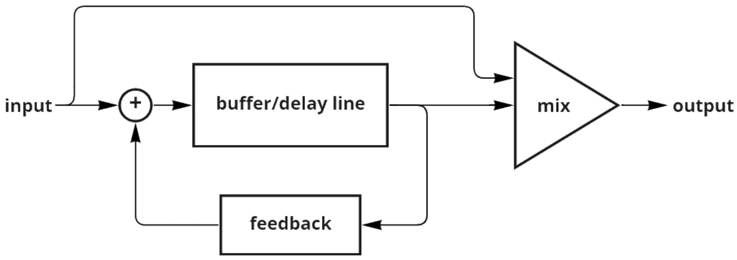


Figure 3.2: delay block

3.1.3 Low Pass Gate

The Low Pass Gate is a combination of a Voltage Control Attenuator or "VCA" and a Sallen key low pass filter. As soon as there will be a control voltage modulating the output of the signal, the filter will start rising the high frequencies. When the control voltage starts fading out the filter will start dumping the high frequencies. Analog Low Pass Gate circuits are based on vactrols components which are a package for a Light Emitting Diode and on the other side there is a Light Dependent Resistor[4]. This component adds a little envelope or "tail" to the sound as it drives the LPG decaying slower due to the light dependency. In the SeeSaw digital implementation a LPG circuit will be simulated based on the paper "A Digital Model Of The Buchla Lowpass-Gate"[25] as there is a need to provide some analog feeling nuances to the digital core.

3.2 Communication Protocol

3.2.1 MIDI

MIDI initials stand for Musical Instrument Digital Interface and it is a protocol that aims to communicate and synchronize two or more electronic musical instruments as well as computers. The MIDI protocol[10] does not transfer audio signals, but instead it transfers bits that contain information about the pitch and the velocity of a note, as well as control and timing signals that determine the speed of a music piece. The MIDI code consists of 8-bits and is transmitted serially from one device to another. Also, because MIDI can send information to more than one device at the same time, the solution for controlling each device individually is achieved by using the MIDI 16 channels. The MIDI Protocol will be used in this project to track with an external controller the frequency of the SeeSaw instrument. The MIDI serial UART code looks like the binary code below.

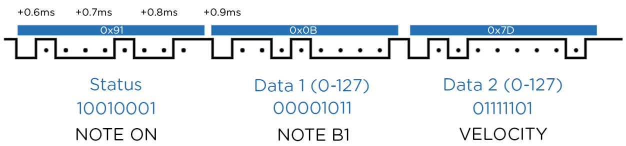


Figure 3.3: Midi byte stream

3.2.2 Control Voltage

Control Voltage is the "common language" which synthesizers use to communicate control functions to each other. The abbreviating used for control voltage in literature is "CV". The control voltage signals are transmitted through patch cables. For instance, in the Eurorack format these cables should be 3,5mm monophonic plugs. Often, the CV inputs of a synthesizer are summed in the electronic circuit with a knob parameter. A usual application is when the user can externally send some CV to a filter section of a synthesizer and manipulate the filter's cutoff frequency from a distance, without touching the relevant filter knob[5]. On the same way, a synthesizer section that generates a CV internally in the circuit can provide the voltage on an output jack. In general, the circuits that generate CV signals are called "Modulators" because of they can morph the sound of a synthesizer with their high and low voltages range. Below, some of these sections that will be used in this project are presented.

3.3 Analog Modulators

3.3.1 Envelope Generator

An envelope generator or "EG" creates a non periodic voltage signal on time. This type of modulator is a necessary feature in SeeSaw as it shapes the loudness of the Complex Oscillator and creates nuances on the existed sound. More specifically, the envelope type that will be analyzed in the present research is the Attack Release envelope or AR. The EG is activated by a very short pulse signal which is called gate signal. When a gate or a trigger signal triggers the EG, a voltage rises from 0V to the maximum adjusted level[5], which is usually between 5-10 Volts. The falling period is called Release or Decay and it starts from the maximum attack position until the voltage curve reaches back again to the 0V.

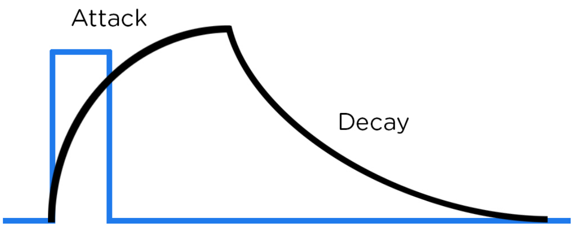


Figure 3.4: Gate and Envelope shape

3.3.2 Low Frequency Oscillator

Low Frequency Oscillator is the second "Modulator" to analyze in this project. Low frequency oscillator or LFO, generates a periodic low in frequency waveforms. The SeeSaws waveforms have eight different shapes such as triangle, sine, square, pulses, random voltages and their mixes. Usually, the frequency range is below audio rate, a typical range can vary between 0.5Hz - 300Hz[17]. LFO is used as an output control voltage for modulating the Voltage Controlled Oscillator and achieve frequency modulation. One of the most famous configuration is to adjust with an LFO the last section of a synthesizer which is called Voltage Control Amplifier or VCA which is the volume attenuator of the system. This configuration creates a tremolo style effect on the main output signal as it can be seen on the figure below. The LFO can be also synchronized with external clock signals to provide rhythmic patterns which are useful for a live performance.

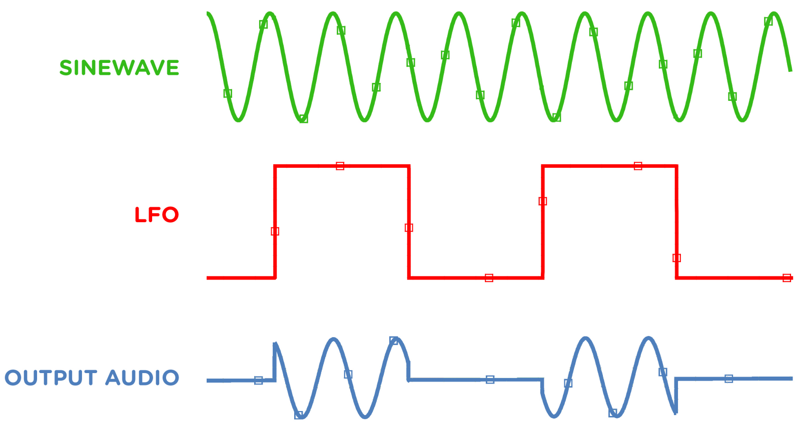


Figure 3.5: LFO modulation of a VCA

3.3.3 Mixer

The mixer is an utility tool in a synthesizer interface. Its basic function is to mix two or more signals by adding their waveforms and their amplitudes[17]. Then the mixed signal can be fed into any audio or CV input of a system for manipulating with the mixed signal the relevant section. The presented in this project mixer is called attenuverter because it is bipolar, meaning that its output can be attenuated both in the positive side of the Cartesian coordinate system but it can be also only in the negative.

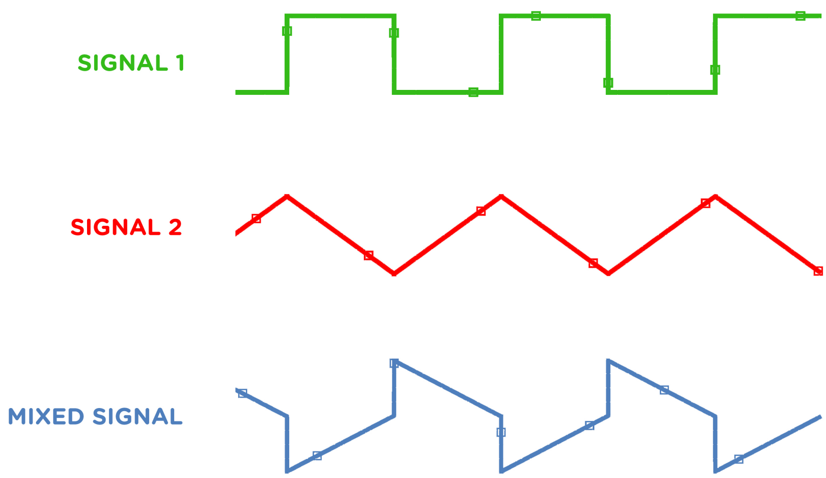


Figure 3.6: Output of mixed signals

3.4 Embedded Platform

The embedded platform used in the SeeSaw development is a company's called Electrosmith[27], which they have released in 2020 the Daisy Seed platform. A specifically designed microcontroller for audio processing applications where the computational power for complex DSP algorithms is achieved. Daisy Seed is based on ARM Microcontroller[1] and the electronic embedded platform is an open source product. In detail, Electrosmith provides the schematics on how to implement the electronic circuits for processing audio and prototyping. For instance, the microcontroller works at 3.3 and 5 Volts but the control voltages signals that have been described earlier are 10Vpp. The available electronic circuits make sure that the operated voltages will be scaled down to the embedded system operating voltages. The advantages of the technical characteristics are presented below.

- Audio algorithms can be programmed in C++, Arduino, Pure data and Gen∼, indeed it creates a lot of flexibility to young audio programmers.
- Stereo audio Input Output up to 96kHz / 24-bit audio hardware
- ARM Cortex-M7 MCU which runs at 480MHz
- Under the hood, Electrosmith have created libraries which process serial, MIDI and OLED screen communication.
- The digital to analog and analog to digital converters generate high quality stereo inputs and outputs.

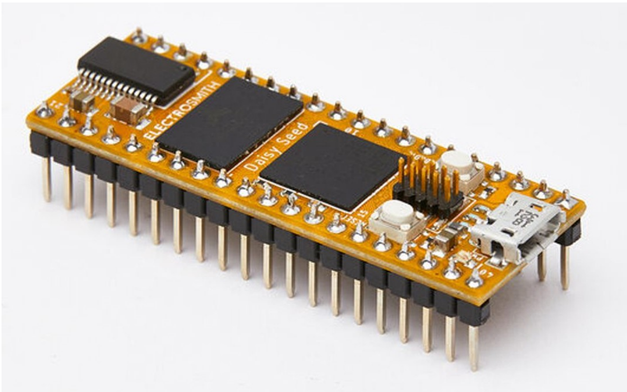


Figure 3.7: Electrosmith Daisy Seed embedded platform

3.5 Algorithm Development

The research objective is pursued through Graham's Wakefield published paper in International Conference on New Interfaces for Musical Expression, in which he describes the potentials of Electrosmith Daisy Seed, the paper is called "A streamlined workflow from Max/Gen∼ to modular hardware"[32]. The method which is presented in this project builds upon Graham's work on the streamlined workflow through Max/Msp ∼ interface which erates the code and flashes it into the Daisy Seed microcontroller immediately.

3.5.1 Algorithm

The audio engine has been developed in Cycling '74 ∼ environment which is an extension for Max/MSP, a visual programming language for music and multimedia. The programming is happening by creating object boxes and by connecting them with cables. One other thing is that ∼ works with one sample at the time instead of operating on a block of samples[32]. That sets ∼ an efficient real time low-level Digital Signal Processing plugin within MAX.

3.5.2 Oopsy

Oopsy has been developed by Graham Wakefield, Cycling '74 and Electrosmith and it is an integrated patch which allows the code generation, compilation and programming of Daisy Seed through Max/MSP. It works inside the Max/MSP patch and it generates the Gen∼ patch into binary code which is then uploaded in Daisy Seed platform by USB connection. The Oopsy workflow is described analytically through Graham Wakefield's paper[32].

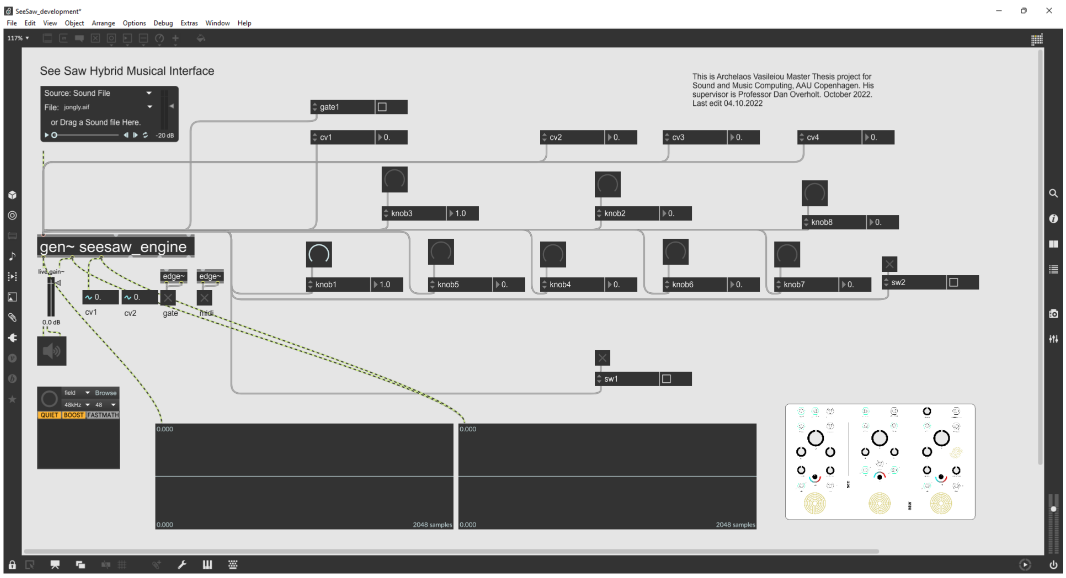


Figure 3.8: Oopsy patch and mapping preface

3.6 Hardware Development

The hardware prototyping process always demands a detailed research for supplying all the necessary hardware electronics components, starting from an idea to a complete musical instrument, the process requires careful selection of components. Among with that a pre mapping of the interface design has been considered in the development of electronics to follow the same design rules and crates faster implementation avoiding errors.

3.6.1 The electronics design

All of the electronics circuits have been prototyped in the breadboard. The breadboard is a tool for building temporary circuits by using through hole mount electronics. The schematic diagrams of Electrosmith field desktop synthesizer have been used for the development of the control voltages, MIDI communication and the input buffer amplifiers which provide electrical impedance transformation between two circuits. Moreover, the analog modulator circuits have been developed and tested for the smooth operation with the Daisy Seeds MCU. A special power supply stage have been designed to cover both the consumption requirements for the analog bipolar power as well as the digital one.Along with the electronics development an analog semi modular synthesizer has been used as a sound source for testing the communication protocol between the different modulators. At this point an early touch resistance sensor has been implemented with copper tape and a piece of cardboard to simulate the haptic controls of the musical interface instrument.

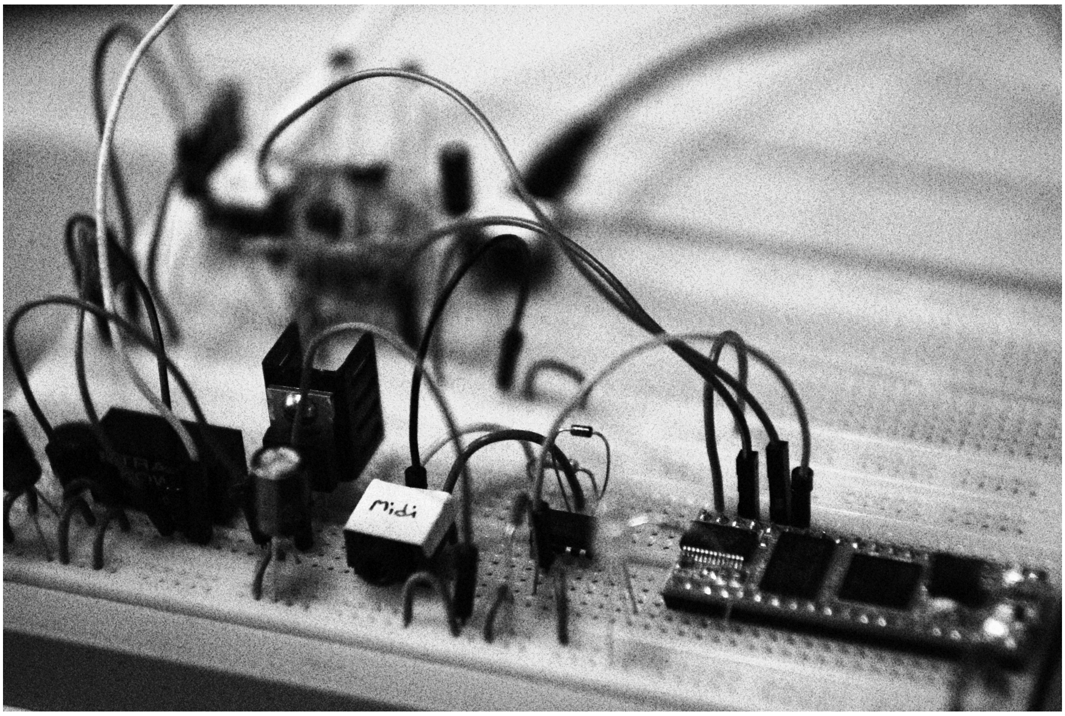


Figure 3.9: An angled view of the breadboard

The KiCad which is a software suite for electronic design automation[9] is used in the presented project for prototyping the electronics printed circuit board. The schematic of the electronics has been started at the time that the experimental breadboard prototype has finished of the breadboard prototype. The verified circuits were transferred immediately to the KiCad's schematic editor.

3.6.2 Interface Design

So as to solve the problem of designing a synthesizer instrument interface where the control over the parameters are mainly buttons and knobs, some gestural "active" elements for interaction have been added, drawing inspiration from similar research such as "The Overtone Violin" from Daniel Overholt where the researcher keeps the expressive elements of the violin but he augmented the instrument with sensors so as to enhance the gestural control of the instrument[21]. However, the hardware buttons are replaced with sensors in SeeSaw design and copper touch plates have been designed specifically for this instrument. The design is inspired from Don Buchla's devices but also from Newton Armstrong who's research contributes to an enactive approach on designing digital musical interfaces[16]. More specifically, Armstrong he sets the research question how to strengthen the human-computer interface interaction as it is often excludes the embodied activities. In return this research through its enactive design reinforces the tactile experience by appealing the user to express his/her musicality or inspiration through Seesaw's enactive interface.

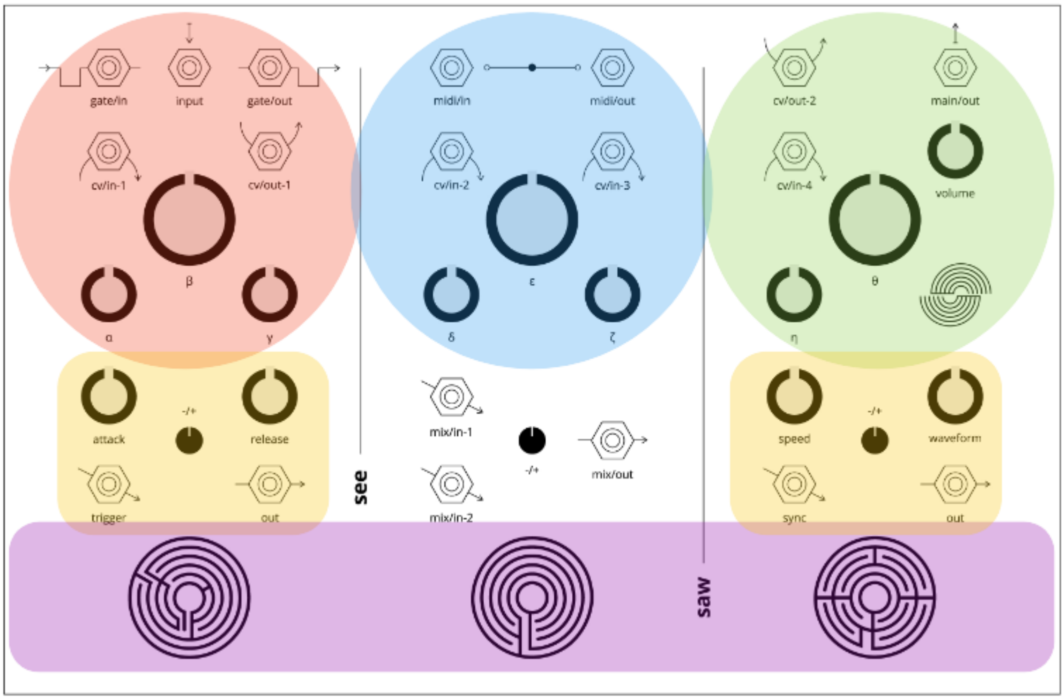


Figure 3.10: Gestalt theory applied on the interface design

The design of SeeSaw is also inspired from Synthux Academy[30] where Roey Tsemah interview synth designers and he gives a lot of hints about designing a synthesizer interface. Among with Winterbloom[11] Synthux inspired a lot the designing of the printed circuit board interterface. Furthermore, the musical instrument's interface is designed based on Gestalt school of psychology theory. The theory is based on how the human naturally perceive the world as perceptual groups and how they experience similarities and differences between elements[14]. The Gestalt principles used in the designing of the SeeSaw are three according to the depicted image below. The first is the law of common region and as it is depicted in the figure the red, blue and green are three different regions separated with two lines, these regions are all digital. The second law is this of the similarity in which the components on the two yellow blocks are distributed on exact the same way to show their similarity, both of these two sections are the analog modulators. The third law is the continuation as it is depicted in the purple block on the bottom. The circular touch plates create a solid continuous as they have the same shape and they are grouped together in the bottom of the interface. The principles are finally grouped based on perceived sonic similarities or categories.

Figure 3.11: SeeSaw hybrid musical instrument

Chapter 4

Design Implementation

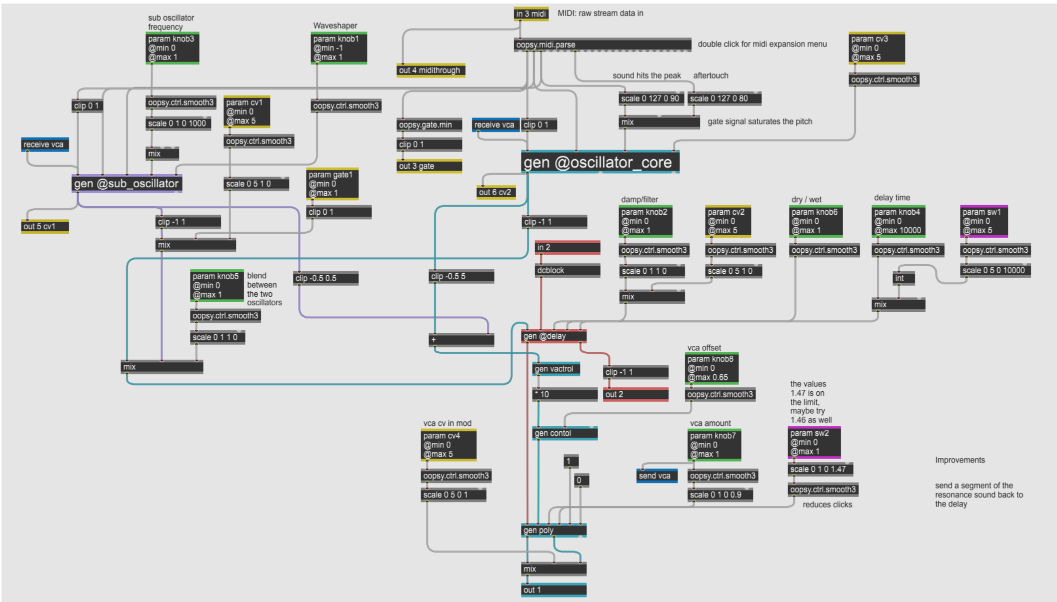


Figure 4.1: Gen∼ main patch for the SeeSaw's audio engine

4.1 Digital Design Implementation

The digital design and the development of the Gen∼ algorithm has been made possible through Oopsy patch. The synthesis has been developed inside the main "Gen∼ seesaw engine". The depicted figure 4.1 depicts the central spine of the algorithm. All of the "gen" objects contain a subpatch code part. For instance, the oscillator which will be analyzed first, is located inside the "gen @oscillator core patch". The aim for this workflow is clearly to organize the different audio processing sections accordingly to the main block diagram where the signal flow through the different blocks. In addition, in the main patch there are only user parameter which are called "param" and they are followed by a minimum and a maximum value, usually are within the range of 0 and 5 Volts. The user parameters values are mapped to the MCU hardware interface and they are mapped to the potentiometers, the control voltage 3,5mm Eurorack standard input and output jacks and the two out of four touchplates which are called switches "sw1" and "sw2". Other than that, some signal calculations are made with the objects "mix" and "+". The clip object adjust the input value in the defined range. For instance, "clip -0.5 0.5" means that the signal is going to be manipulated within this value range. The "dcblock" is a simple one pole high pass filter which removes dc components from the signal chain since in the analog world this would be similar to the capacitor coupling technique.

4.1.1 Digital MIDI

The MIDI is received through Oopsy's object midi parse in a form of raw streamed data. The bytes then are distributed within the "oospy.midi.parse" object according to the data note, gate signal, velocity etc. In this project the gate signal which is 0 or 1 is activated when a key or pad of the MIDI controller is pressed down. The pitch which is an integer 0-127 bytes MIDI note value is used for deriving the Oscillator's frequency and the velocity which is normalized to 0 and 1 is used for attenuating the amplitude of the pitched note. Aftertouch function are added to the code as well where the velocity manipulations can be achieved while the controller key is held done. The MCU sends out processed MIDI data streams to an output 3,5mm jack if an additional MIDI device needs to be controlled.

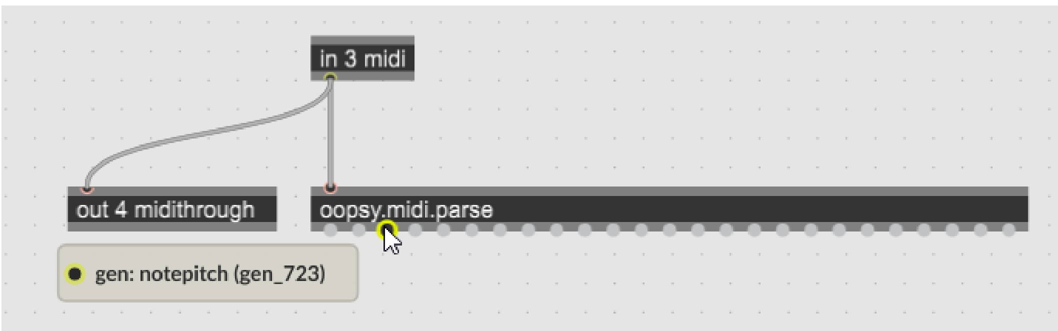


Figure 4.2: Oopsy.midi.parse object in Gen∼

4.1.2 Hardware MIDI

Using the KiCad schematic editor the prototype MIDI circuit has been transferred from the breadboard to the implementation for the printed circuit board. The MIDI raw stream byte is received from the MIDI controller through the input 3,5mm audio jack. The bytes stream it is transmitted to the Microcontroller through the schmitt trigger output optocoupler[**empty citation**]. The optocoupler isolates the received MIDI stream by flashing the bits 0 and 1 through a LED, the schmitt trigger receives the bits and it translates it into universal synchronous and asynchronous receiver-transmitter serial communication protocol which the Microcontroller Unit "MCU" can handle due to the installed MIDI libraries. At the same time the MIDI output has been connected to the MCU to transmits output MIDI messages to an external device.

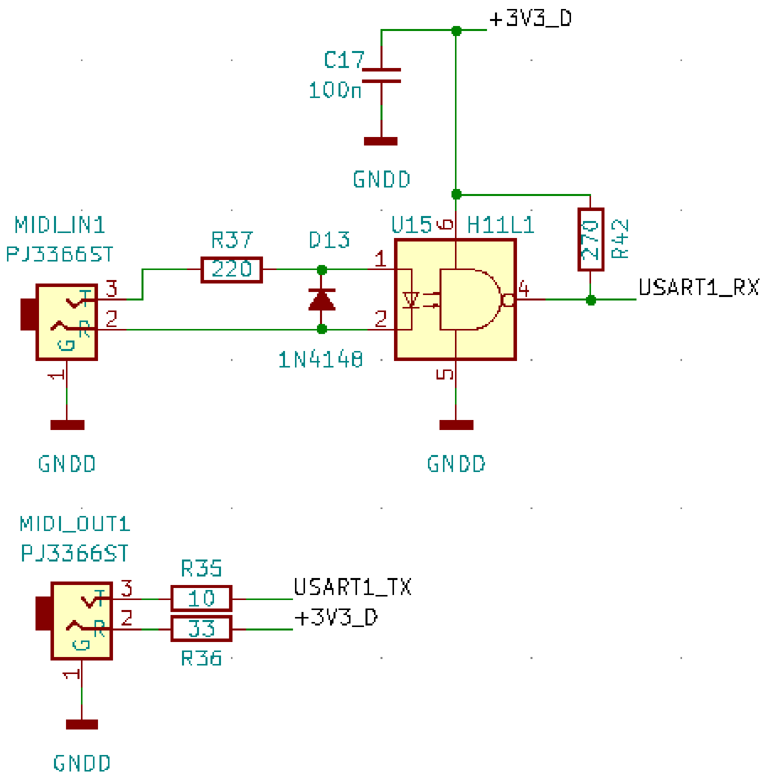


Figure 4.3: Schematic of the MIDI configuration

4.1.3 Oscillator Patch

The MIDI functions are mapped to the complex oscillator engine. The gate signal means that the user has pressed a key or a button through a MIDI controller. Diving into the oscillator subpatch, the pitch data information are fed into an envelope filter with 100ms raising time and 300ms falling time. The envelope filter and smooths out the incoming stream of bytes. The object "mtof" converts the midi notes 0-127 into frequency measured in Hz. Then the frequency in Hz is fed into a phasor object which generates a sawtooth waveform. The generated sawtooth has an amplitude of -1 1 to avoid any hard clipping. If further reduction of the waveform's amplitude is needed the mix object can be controlled by a float number, in this case is 0.3. At the same time the gate and the velocity number are multiplied and they are shaped through a simple envelope filter as to avoid digital click noises. The waveform it is then multiplied with the envelope filter and the output waveform is a clean sawtooth as it is depicted in figure 4.5. An external input4 carries control voltage signals from the interface. The input is scaled and only the integer numbers are allowed to pass through. If a control voltage will be applied in input4 the CV will be added and alter the Oscillator's frequency in round notes because the "int" object creates fixed intervals. Then every integer number is converted into frequency with the "oopsy.cv2hz" object. The frequency is multiplied with the "mtof" object's right input which tunes the overall frequency. This is the first of the two oscillators, although the sub-oscillator which is the second one is identical to the first one, there are some additional connections outside of the oscillator patch.

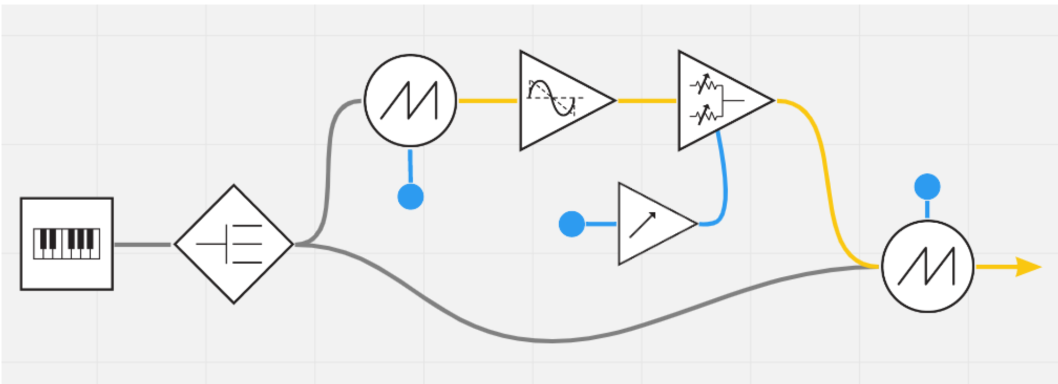


Figure 4.4: Complex oscillator block diagram

4.1.4 Complex Oscillator explanation

However, that sawtooth signal sounds very repetitive and there is no analog nuances on it. For this reason, in the external main patch, the mapping of the two

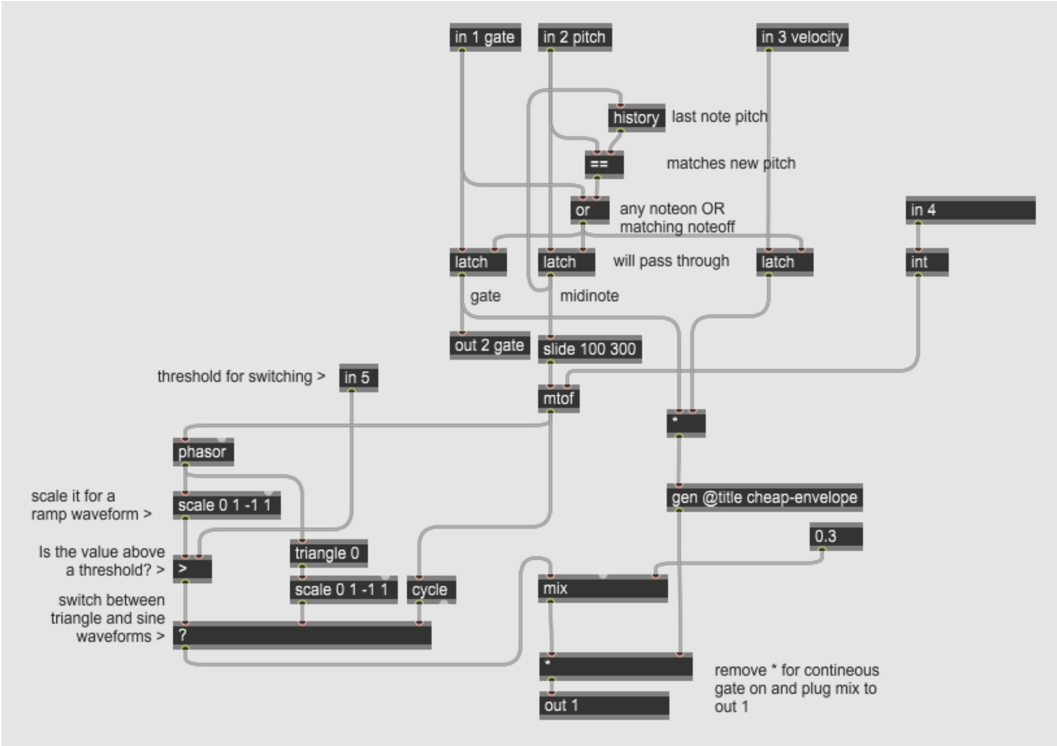


Figure 4.5: Complex oscillator Gen∼ patch

oscillators is synthesized based on the Buchla's block diagram for Music Easel. Both of the oscillators are tracked by the midi events such as pitch, gate and velocity. That means both oscillators by default are synchronized and tuned to the same fundamental frequency. However, the first oscillator is normalized to the second oscillator. In the Buchla Music Easel synthesis the modulation oscillator modulates the complex oscillator if that is wanted. In the SeeSaw, the main oscillator is modulated by the modulation oscillator and it creates frequency modulation effects, which they can be tracked on frequency. The importance of the first oscillator it is described through the gen patch. The fundamental functions of the sub-oscillator patch are similar to the main oscillator except that there is a waveshaper configuration. The sawtooth waveform is transformed into a triangle shape waveform. Moreover, the MIDI frequency is fed into a sine wave generator which is finally mixed with the other two signals the sawtooth and the triangle. An external potentiometer with a range between -1 0 1 decides which waveform type will be mixed in the output of the patch.

4.1.5 Delay effect

The delay line is stereo and it is based on two buffer lines of the sample rate. The input signal is fed into the delay line where it is stored always accordingly to the samplerate which is here 44100kHz. Practically, a delay line controls the time between every repeat. Then, the damping controls the number of the repeats where a portion of the output of the delayed signal is routed back into the input and the delay gets quieter each time and eventually the sound dies out in decaying echoes. Last, the mix section controls the blend between the dry and the delayed signal. The patch in figure 4.10 is corresponding to the basic delay block diagram. Some of the object are widely used in the Gen∼ patch such as the clip -1 1 which reduce the signal within these two values.

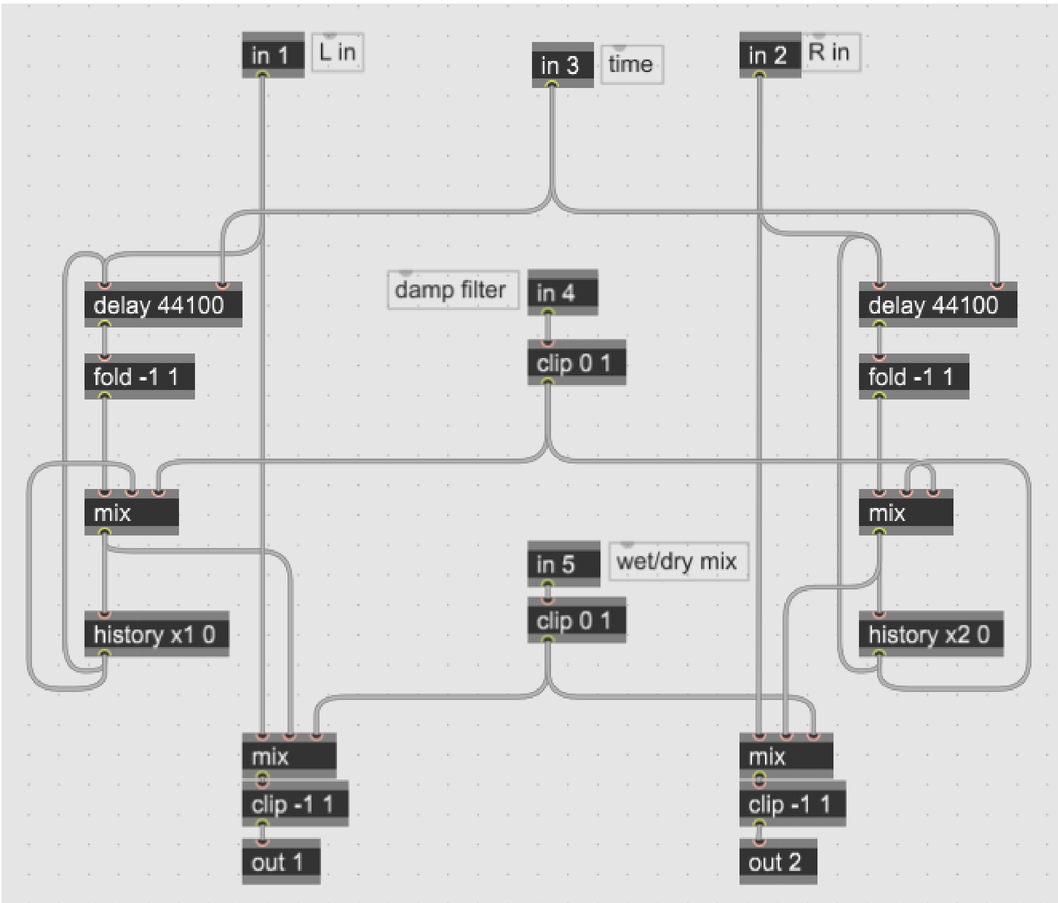


Figure 4.6: gen patch of the delay lines

4.1.6 Low Pass Gate

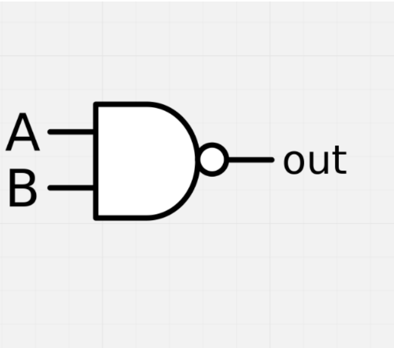
The Low Pass Gate is Julian Parker's and Stefano's D'Angelo research on "A Digital Model Of The Buchla Low Pass-Gate"[25]. The Buchla circuit produces quick plucked sounds which are similar to the natural pluck sounds. The model is a digital emulation of the electronic circuit analysis. The transfer function of the different circuit blocks which describe the electrical behaviour of the circuit are used as digital models. The model it is described as computationally inexpensive and it provides analog nuances. The Gen∼ patch consist of three different subpatches, the vactrol optocoupler, the voltage control attenuator and the low pass filter. The current algorithmic block has been used as it is and only the inputs and the outputs have been alter to match the overall sound synthesis design of SeeSaw instrument.

4.2 Analog design Implementation

The analog circuits are powered according to the Eurorack standard with a bipolar -12V and +12V. That helps to achieve a better communication in sending control voltages between SeeSaw and external synth devices to play together. The digital circuits are powered by two isolated 5Volts regulators. The first regulator powers the digital circuits and the second one biases some audio inputs. Separated power sources needed for minimizing the interference in the audio signal path. For keeping the analysis of the analog electronics short and solid, some parts will not be explained as they are not playing an important role in the synthesis technique. These circuits are the power supply, the Microcontrollers buffers for biasing and balancing the input and output control voltage signals and last the push pull transistor based true stereo audio amplifier. However, if it is in your interest there will be a documentation of these blocks of the schematic in the Appendixes.

4.2.1 Touch-plates

There are four haptic pads in SeeSaw. They are all used as part of the en-active control between the user and the machine. The circuit is based on a NAND gate. This gate is exactly the opposite of an AND gate,because its topology is an AND gate in series with a NOT gate. According to ST Microelectronics Semiconductor manufacturing[28] the touch sensors can be any shape but it is recommended to be round as the electrodes will have approximately the same capacitance. The first objective is that the sensor needs to be of the size of the human fingers. Since the detected object here is the finger the recommended copper track thickness should be at least 0.2 to 0.3mm, but in our case is 1mm for the thick pads and 0.254mm for the thinner small pad. The circuit is fair simple and efficient, the two ports A and B are powered through a 4,7-10Mohm resistor. The one electrode is connected to the ports and the other is grounded. As soon as the finger will short the two electrodes a differential voltage will be occurred in the AND gate input and from the state where A + B = 0 will change to something else, since the finger is not the perfect conductor, but in case of NAND anything else gives back an A + B = 1. The output will be high and a voltage will be raised in the output of the gate. This voltage is processed as a trigger signal for the Envelope Generator and as a tap tempo button for the Low Frequency Oscillator. The other two pads are connected in the microcontroller and they are used inside the Gen∼ patch for switching different parameters of the code.



A	B	OUTPUT
0	0	1
0	1	1
1	0	1
1	1	0

Figure 4.7: NAND gate table

4.2.2 Envelope Generator

The envelope generator it is inspired by Jonathan Jacky back from 1980 and later Yves Usson[3], a modified version is used in Arturia's Microbrute synthesizer. However, the circuit has been modified again this time in order to be simplified and the efficient, following the Buchla's simple Attack Release or Attack Decay circuits philosophy. The envelope receives a gate or trigger signal which later fires the timer 555C. This generated signal passes through 2 different "shape" conditions, the "attack" and the "release" condition. The two conditions can be altered by tweaking the potentiometers. The waveforms are occurred because of the charge and the discharge of the electrolytic capacitor C16 with value 10uf. Let's assume that the circuit is in a relaxation and the capacitor is discharged. When a gate signal will trigger the pin 2 of 555 chip the output on pin 3 will be as high as the power supply is, so 12V. The 12 Volts will charge the capacitor C16 through the diode and the attack potentiometer, when the voltage will be decreased in the 555 chip the output on pin 3 will be low at 8 Volts due to the internal 555 voltage divider, the capacitor will be discharge through the release and the discharge pin of the 555 timer chip. In the meantime if a new trigger will be occurred in the pin 2 a new charge will start obtaining the previous condition.

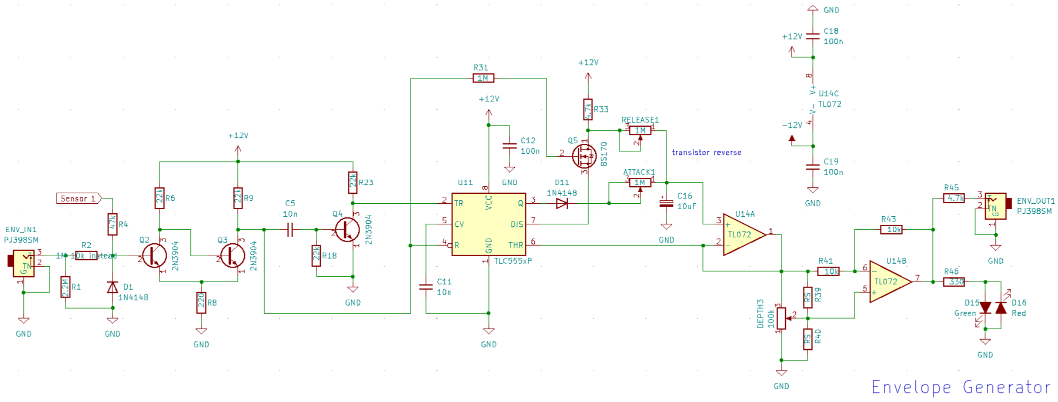


Figure 4.8: Envelope Generator schematic

4.2.3 Mixer

The mixer in this project is actually an attenuverter. Attenuverter is both an attenuator but it is also an inverter, which means it can reduce the amplitude of a signal as an attenuator but it can also invert the phase of it[**skull**]. That simple circuit is very useful for signal processing in synthesizers and it has been used both in the outputs of the Envelope Generator and the Low Frequency Oscillator. The first mix input 1 is always inverted through the negative input pin 6 of the operational amplifier but the mix input 2 it can be inverted but also, as some portion of the signal can be fed through the potentiometer sum1 in the positive pin 7, it can be only attenuated having the same phase. The LEDs are connected opposites and they blink according to the output state of the signal, negative or positive.

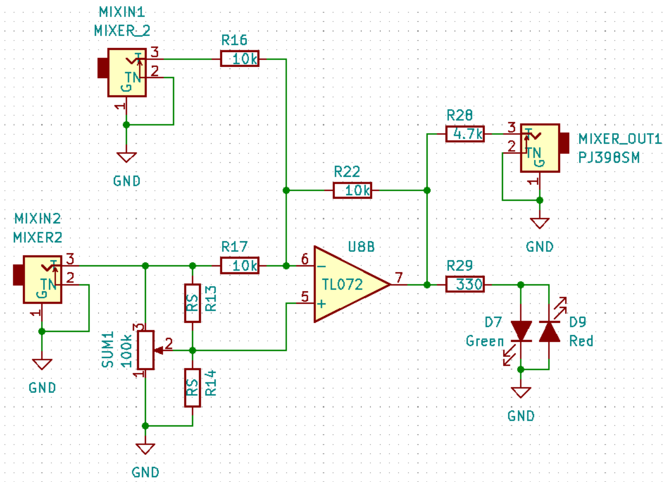


Figure 4.9: Mixer schematic

4.2.4 Low Frequency Oscillator

The Low frequency Oscillator is based on a programmable PIC Microcontroller which has been developed by Electric Druid company. This particular chip has been used for saving space in the design but also it offers huge flexibility as it generates eight different waveforms including random voltages. The LFO can be used as a clock signal to synchronize the envelope generator and as a modulator for different events such as pitch modulation or amplitude modulation by plugin it into the different stages of the instrument. The LFO can be also triggered and synchronized by the MIDI clock in case the rhythmic patterns are necessary. The user can apply tap tempo through touchplate which triggers the LFO to be synced with the finger taping period. Another experimental behavior of the touchplate is that it can be shorted once the finger will apply continuously haptic contact and then the period of the LFO starts crackling and producing experimental sonic patterns.

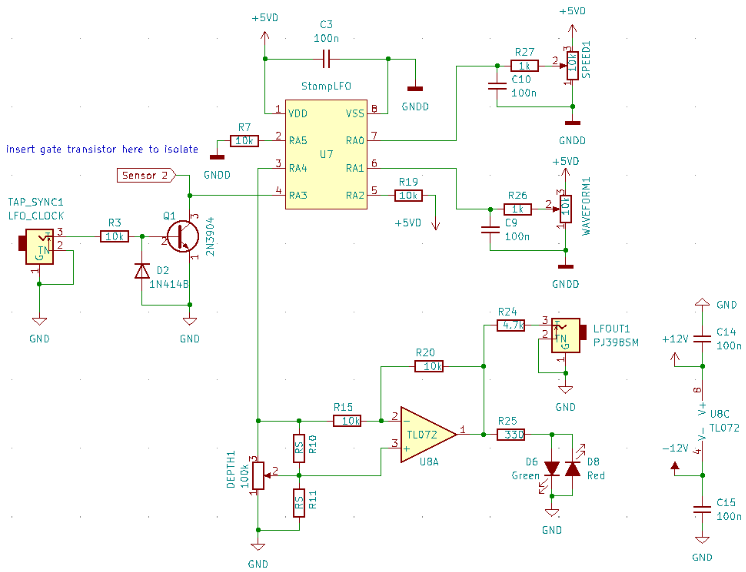


Figure 4.10: LFO schematic

4.3 PCB Production

The full view of the schematic can be found in the Appendixes. All of the schematics have been implemented in KiCad schematic editor after being tested in the breadboard. From the schematic the pcb footprints with all the connections between the components are generated and the components need to be positioned according to the design interface. The printed circuit board is two layers board and since the electronics are mixed, both analog and digital, a star ground method have been used for grounding the printed circuit board different elements[34]. The method suggests the star ground to isolate the digital electronics ground from the analog electronics ground. The two grounds are connected only in a single point as close as possible to the power supply. If the star ground will not be applied, the digital and the analog ground will be mixed in several points in the pcb creating ground loops which they can create noise, hum and interference to the audio signal path. All of the user parameter such as the potentiometer the LEDs and the input and output 3,5mm jack are in the bottom layer of the pcb and all of the electronics components are placed in the top layer.

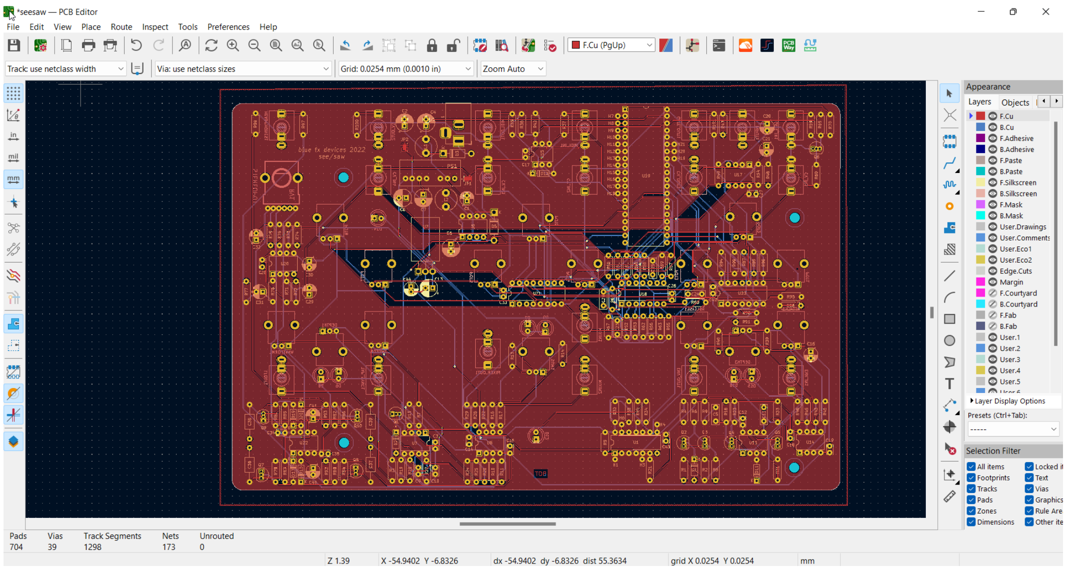


Figure 4.11: SeeSaw pcb in the pcb editor

4.4 Interface Implementation

The user interface has been designed as a printed circuit board because it was more convenient to use KiCad for this particular design. The pcb manufacturer uses fast and automated processes for drilling the holes for the hardware components. In addition the manufacturer applies color mask on the surface and silkscreen printed graphics. The design has empty from color spots in the face masks where the LED light can be diffused through and create a more pleasure interaction for the user.

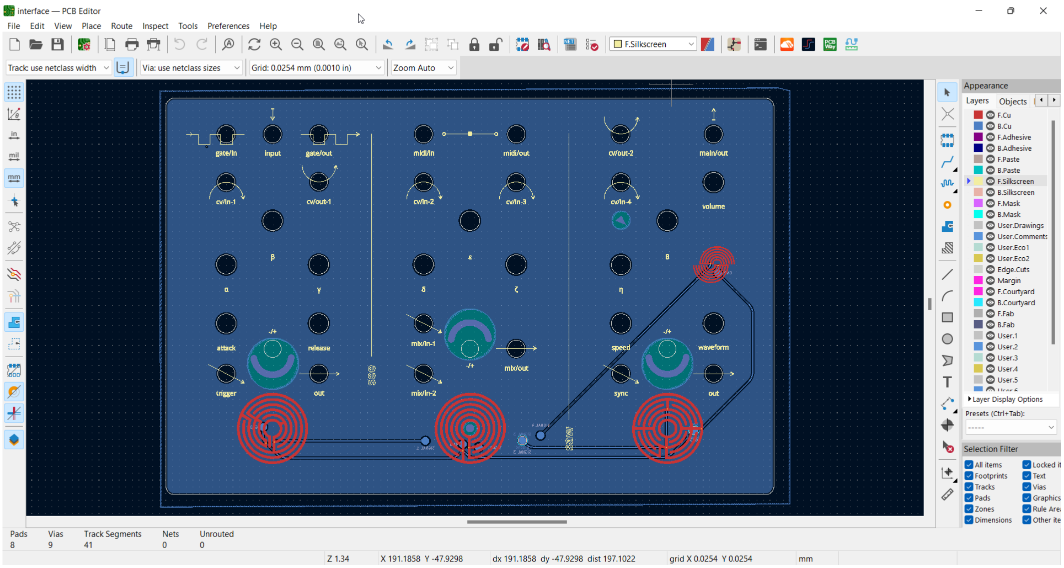


Figure 4.12: SeeSaw 3d view of the bottom layer

4.5 3D drawings

Following the fabrication and prototyping techniques[22] printed circuit board processes the VRML files which contain all the render 3D components have been imported in Rhino where a 3D model for the enclosure has been designed. During the process the interface has been matched with electronics pcb and it was a validation that the design didn't have any errors.

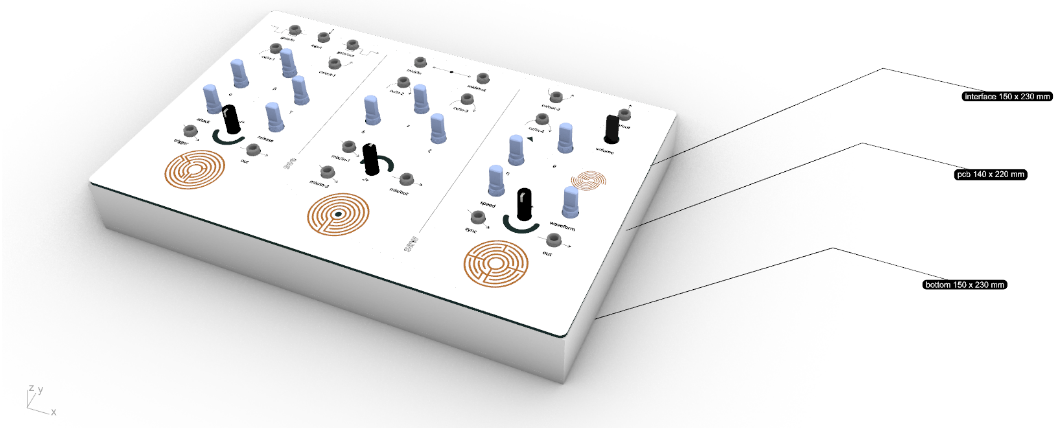


Figure 4.13: SeeSaw 3d angled view in Rhino

Chapter 5

Experimental Results

In this section the digital audio signals which are generated inside the MAX/MSP Gen$\sim$ and they have been captured with the scope object will be compared to the relevant analog signal capture from the physical device. For this purpose an analog USB oscilloscope has been used, but the measured from the device signals were too noisy. An alternative solution found through the VCV Rack[26] SCOPE. The VCV RACK is an environment for simulating a Eurorack system where the user can design the desired sounds through a big class of free modules. Within these modules there is an oscilloscope which have been tested and it is very accurate. The setup of the measurements includes as DAC interface the high quality Universal Audio Volt 274 sound interface and oscilloscope clip probes for measuring the input signal.

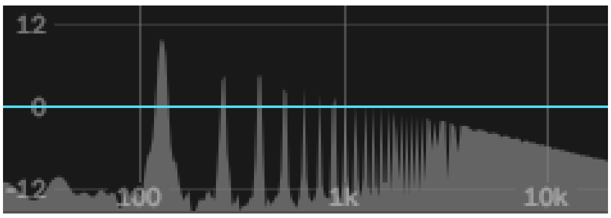


Figure 5.1: Sawtooth harmonics of C3 note

5.1 Oscillator

The sawtooth oscillator waveform have been measured in the MAX/MSP environment for the MIDI C3 note. Similarly, the output of the oscillator has been captured in the SCOPE. The signal of the physical device has an introduced phase and it should be caused due to the output buffers circuit. The rich in harmonics spectral analysis of the oscillator have been captured for the C3 note with fundamental frequency 130.8Hz.

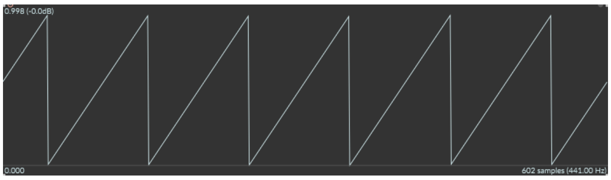


Figure 5.2: MAX/MSP sawtooth of C3 note

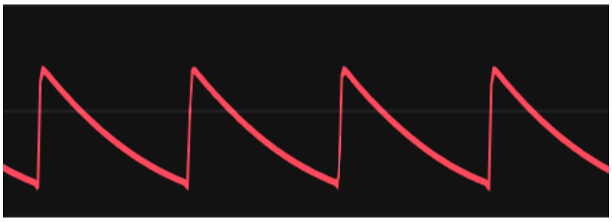


Figure 5.3: VCV SCOPE of C3 note

5.2 Complex Oscillator

The complex oscillator sawtooth waveform have been measured in the MAX/MSP environment for the MIDI C3 note which is the receiver and the MIDI note D2 is the carrier.The rich in harmonics spectral analysis of the complex oscillator have been captured for the C3 note with fundamental frequency 130.8Hz and there on the top of that there is added the carrier frequency D2 73.42Hz. The amplitude of the carrier was on purpose attenuated to capture the two different signal in the oscilloscope.

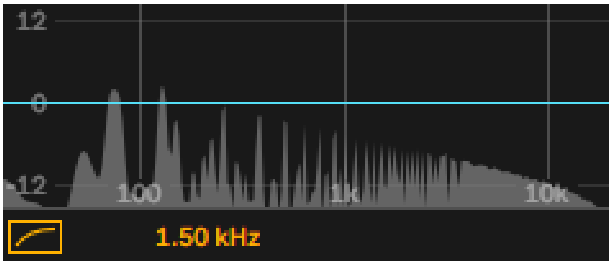


Figure 5.4: Sawtooth harmonics of C3 note

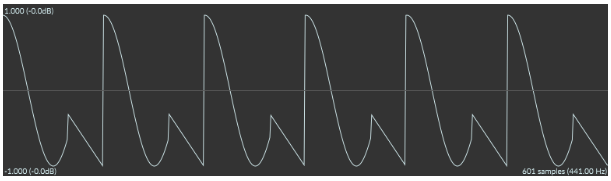


Figure 5.5: MAX/MSP complex sawtooth of C3 note

Figure 5.6: MAX/MSP complex sawtooth of C3 note

5.3 Low Pass Gate

The spectrum analyzer have been used to record the resonance of the filter in the range of 1KHz. Again the MIDI C3 note have been used as a default reference and the two modes have been capture. The figure 5.1 is the spectrum of the oscillator with frequency 130.8Hz and the figure 5.7 is where the user touches the resonance touch plate and he introduced the filters manipulation.

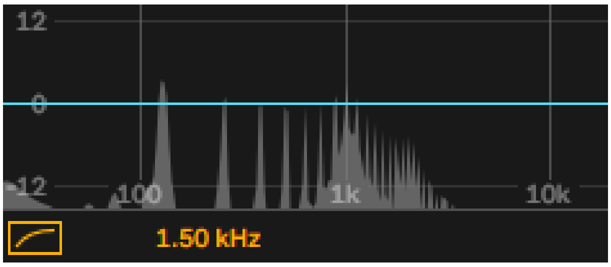


Figure 5.7: Resonated sawtooth of C3 note

Chapter 6

Evaluation

This chapter presents the evaluation process of the SeeSaw hybrid musical instrument. The aim is to map, understand and evaluate the performative capacities of the instrument. The results will be further analyzed and they will be compared to the design aspects, to determine whether or not the research hypothesis has been addressed.

6.1 Evaluation Setup

During the evaluation the following music equipment has been used:

- SeeSaw hybrid musical instrument
- Teenage Engineering PO 12 drum machine
- Arturia Keystep MIDI controller
- Universal Audio Volt 274 sound interface
- Presonus ERIS 5 studio monitors
- Many 3,5mm patch cables for semi modular synths

The SeeSaw synthesizer was powered with a power adaptor of 9 Volts. An Arturia Keystep MIDI controller has been used to trigger the MIDI notes in SeeSaw through a MIDI DIN to 3,5mm cable. The main audio output of SeeSaw was connected to the Universal Audio sound interface. The studio monitor were connected to the audio interface and the SeeSaw's sound could be heard through them.

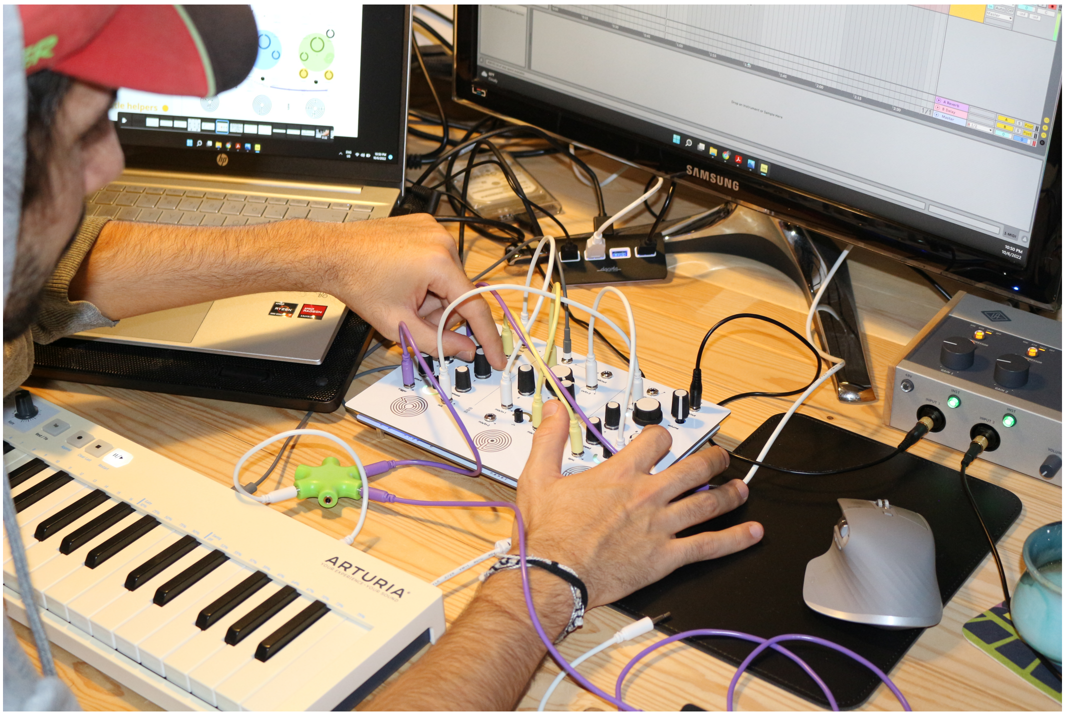


Figure 6.1: Oopsy patch and mapping preface

6.2 Performance Task

The participants were given a very specific task to process within 30 minutes. In total five participants evaluated SeeSaw's interface. Firstly, participants have been asked to evaluate their experience with electronic music production in a scale from 1 to 10. The second question was if they have ever played a semi modular synthesizer before. Next they have been introduced to the performance task. The image on figure 6.2 was given to them and there were no guidance or any further explanation, additionally a batch of 3,5mm patch cables were available for patching. The 1st task was to spend 10 minutes and familiarize themselves with the instruments interface and the instrument's sounds. The 2nd task was to spend 10 more minutes to generate meaningful music patterns that could potentially be used in a music production, a live music performance or art. The 3rd task was coupling the semi modular synthesizer with a drum machine in order to align their produced music patterns along with a tempo stream. During the evaluation process, the participants didn't have any control over the drum machine sounds, except for the tempo which was synchronized to the MIDI Controller. The drum machine sound was a four quarter tempo bass kick drum with few hihat nuances here and there. The last 5 minutes the participants were asked to answer the two main research questions regarding the instrument's performance.

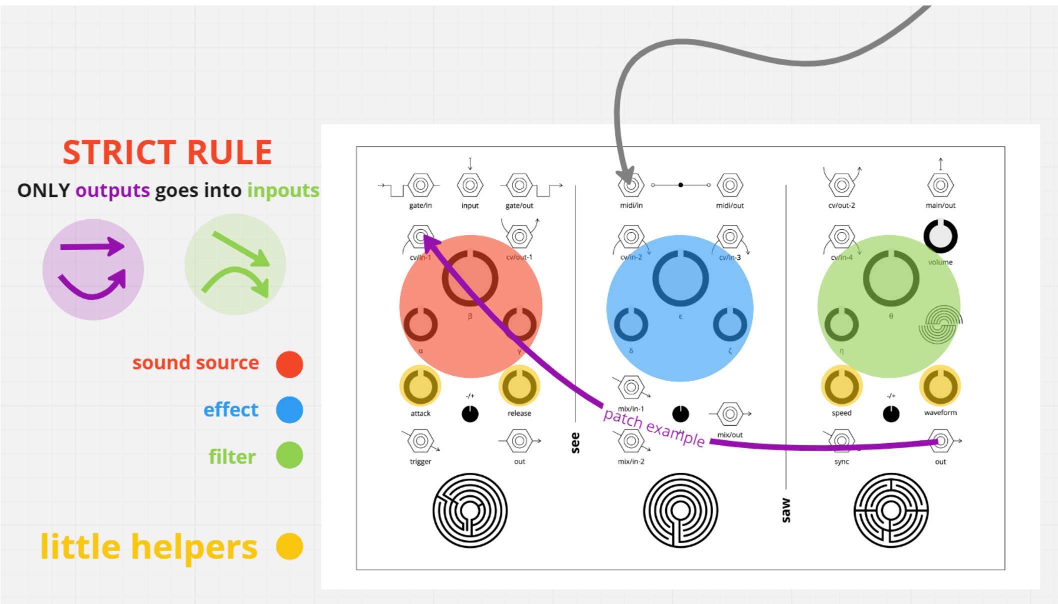


Figure 6.2: Evaluation image

Chapter 7

Results and Discussion

The participants at the end of the evaluation were asked to answer the two major research questions. Five participants participated in total, in two days evaluation and each of them spent 30 minutes in executing the music performance task. Two of the participants were more experienced with electronic music production while the other three were not feeling familiar.

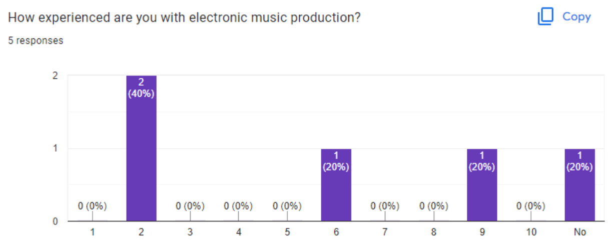


Figure 7.1: Level of expertise

Three of the participants played before a semi modular synthesizer while two of them had no previous experience.

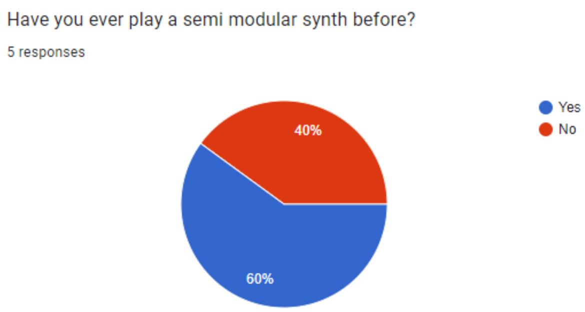


Figure 7.2: Experience on a semi modular synth

7.1 Qualitative Data

All of the participants have managed to replay in the two research questions. Regarding the first question whether or not they have managed to create/compose sounds that you can use for music performance, music production or art, the replies were all positive. Their comments are presented below with chronological order and then they will be discussed later.

- Yes
- I could use some parts of the composition somewhere. Not stand alone main sound.
- Absolutely! I love experimental sounds that go in a direction without solving a very specific purpose. playing with SeeSaw made it fun to aim for a goal without having a direct path in mind.
- Yes
- Yes and moreover I got inspired and motivated on sound design.

The next answered research question was if they explored new sounds with the device's interface, and if they found the interface agile enough to help you them on performing task.

- Yes
- The interface was agile enough, even though I am not familiar with synthesizers. Knobs tags were a little confusing.
- Yes. The interface was confusion and I still think it is, the symbols, I try to not see them but instead look at the visual and auditive feedback, which was really cool. In playing the interface I would say it was agile, at least it is responsive and well mapped so it was easy to have fun once the first initial patching was done.
- Defenitely
- Yes, about 90 percent of the sounds generated were new for me. The interface was more than agile enough to get inspired and get lost in the sound.

Finally, the participants were asked to comment freely their experience, they could give feedback to anything they do like and anything they didn't perceive as a nice experience.

- Despite being unfamiliar with synthesizers, the interface allowed me to create musical patterns that could potentially be further explored and developed.
- If you are not experienced, it is hard to find the connection between the source and the effect and filter. Interesting sounds, wide range of possibilities.
- The instrument did not react the way I thought it would which threw me off a bit in the beginning. Then I let it go and just tried to generate cool sounds. This approach would probably be my goto until I get more familiar with the device, especially if the plan was to take it to the stage. But it is like that with any good and expressive device. I had a lot of fun playing with it and I could see myself recording longer jam sessions and snipping out bit and pieces for constructing full compositions.
- I liked the manual patching.
- I've practised a lot with synthesizer VSTs and no matter how many times I've tried, I could not generate a sound that seemed attractive to my ears. With SeeSaw I managed to understand much better the way the sounds could be designed, and got lost in the way the sound are created.

7.2 Discussion and Conclusion

While the evaluation was going on, the researcher was observing the candidates performance and he kept notes that they will be evaluated now together with the general feedback and the research questions. The SeeSaw's experimental synthesis technique is embedded successfully on the Microcontroller unit. The mapping of the musical instrument interface corresponds to the audio core functions and the performance of the hybrid electronics are very stable for this prototype unit. The sound quality have been measured in the chapter 5 in which some experimental fundamental measurements validate the performance of the audio synthesis technique. Based on the responses, the results show that, while participants varied between highly, moderate and non experienced, they all managed to familiarize themselves with the design and manipulate the implemented functions. More specifically, it was observed that all of the participants started familiarizing themselves with the parameters and features of the instrument's interface. During the second performance task, all of them managed to create sounds that they found interesting. However, as an additional observation they were few features that well explored by the participants. As an example, two out of five participants did not fully engage with the touch plates during the first and second task. In return, by the third round of evaluation, all participants had gained a really good insight into the semi modular functional, performative and creative aspects of the design interface and responded positively in the interaction with the added drum machine within the setup. In particular, it was observed that the addition of the tempo, facilitated the understanding and tweaking of the functions, even though the specific parameters were not transparent to the participants. Finally, the evaluation study showed that the design interface can respond in both enactive and creative user's demands, without the need of thorough previous experience nor user's textbook.

7.3 Future Work

The presented research project sets a new path within the experimental field of semi-modular synthesizers, combining both analog and digital electronics through experimental synthesis techniques. Further work will focus on the design interface with the ambition to enhance even further its enactive and intuitive logic. In return, this will facilitate creative music synthesis in more generative way across all ranges of user experience. Lastly, the re-programmable feature is considered to be an extensive future task since there are many challenges that need to be addressed for including user experience.

In case you have questions, comments, suggestions or have found a bug, please do not hesitate to contact me. You can find my contact details below.

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so...be playful!

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Appendix A

Appendix

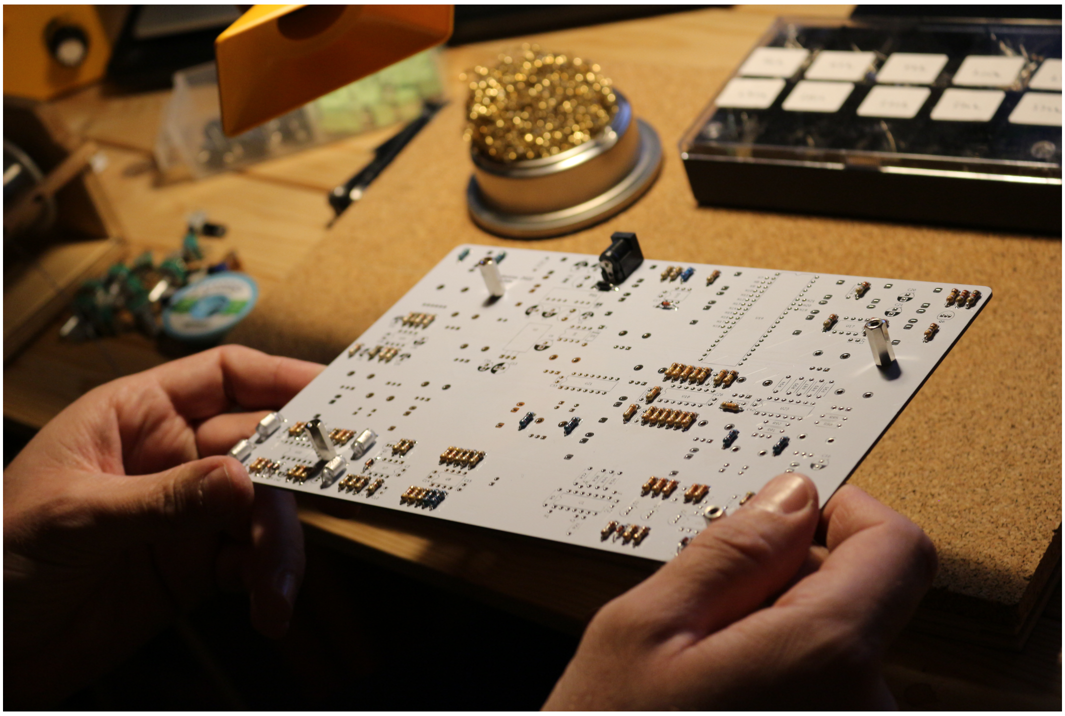


Figure A.1: SeeSaw assembly of the pcb

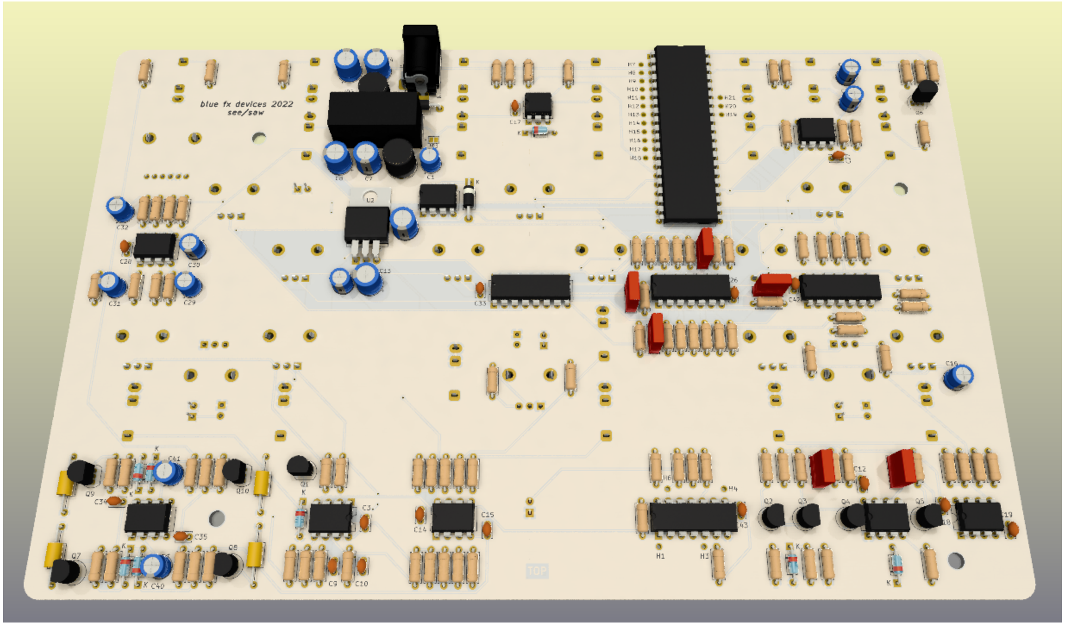


Figure A.2: SeeSaw 3d view of the pcb top

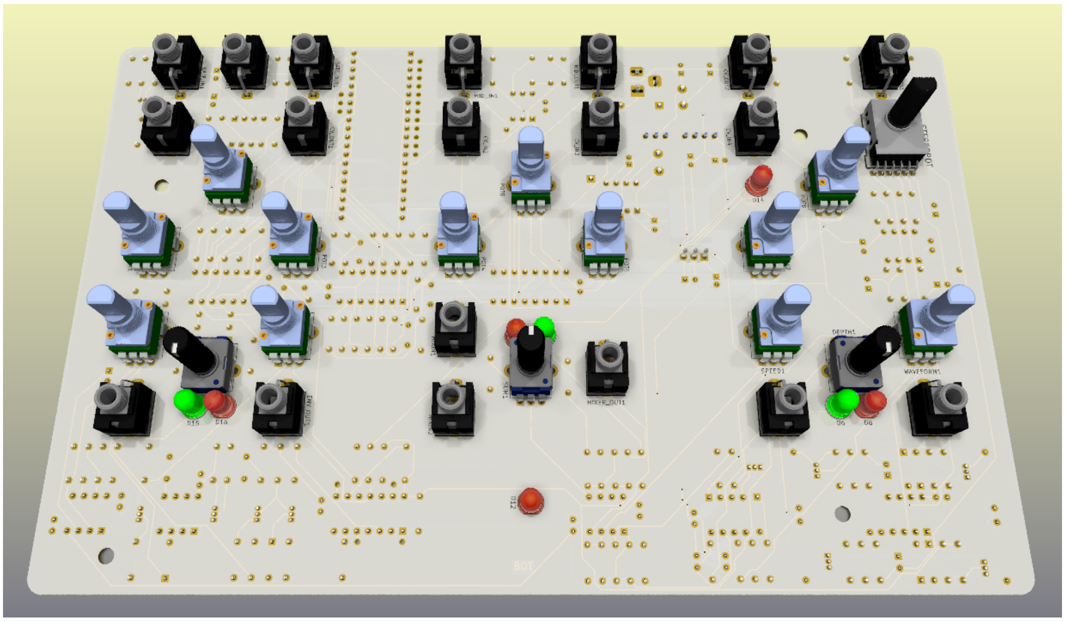


Figure A.3: SeeSaw 3d view of the pcb bottom

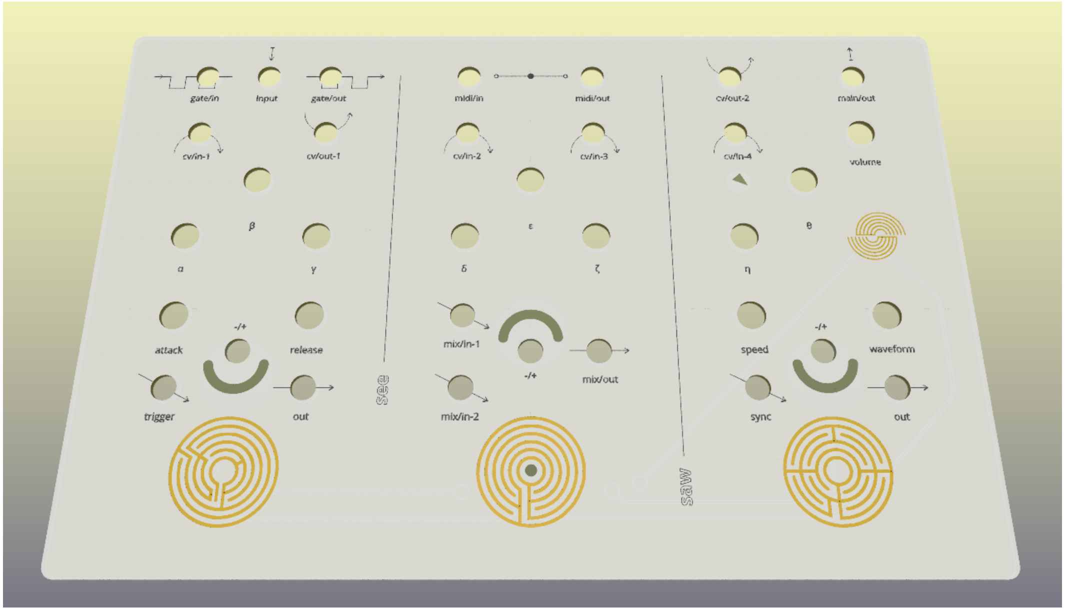


Figure A.4: SeeSaw 3d view of the interface top

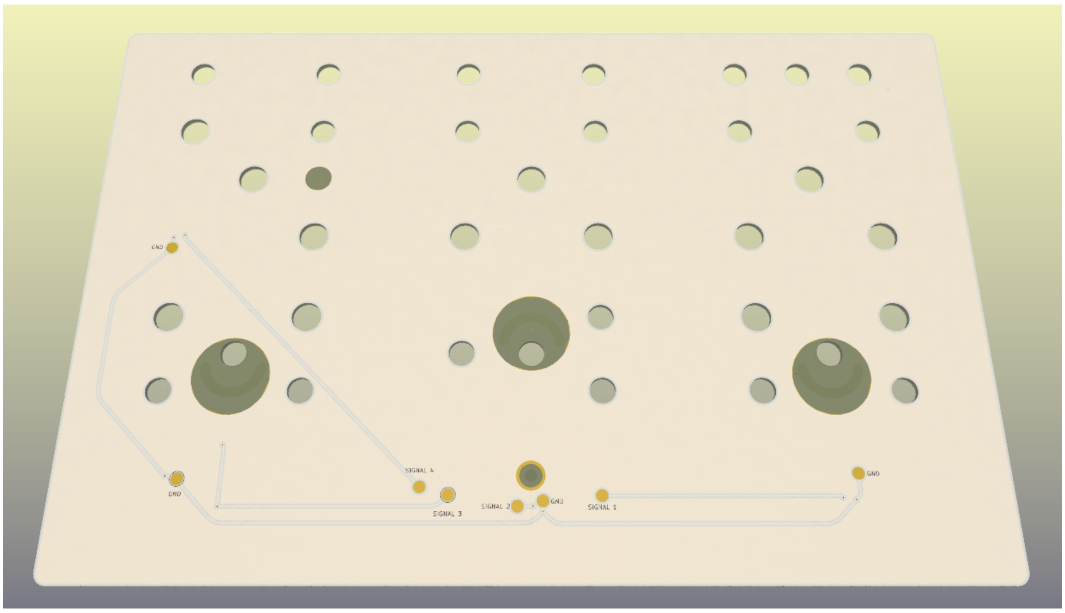


Figure A.5: SeeSaw 3d view of the interface bottom

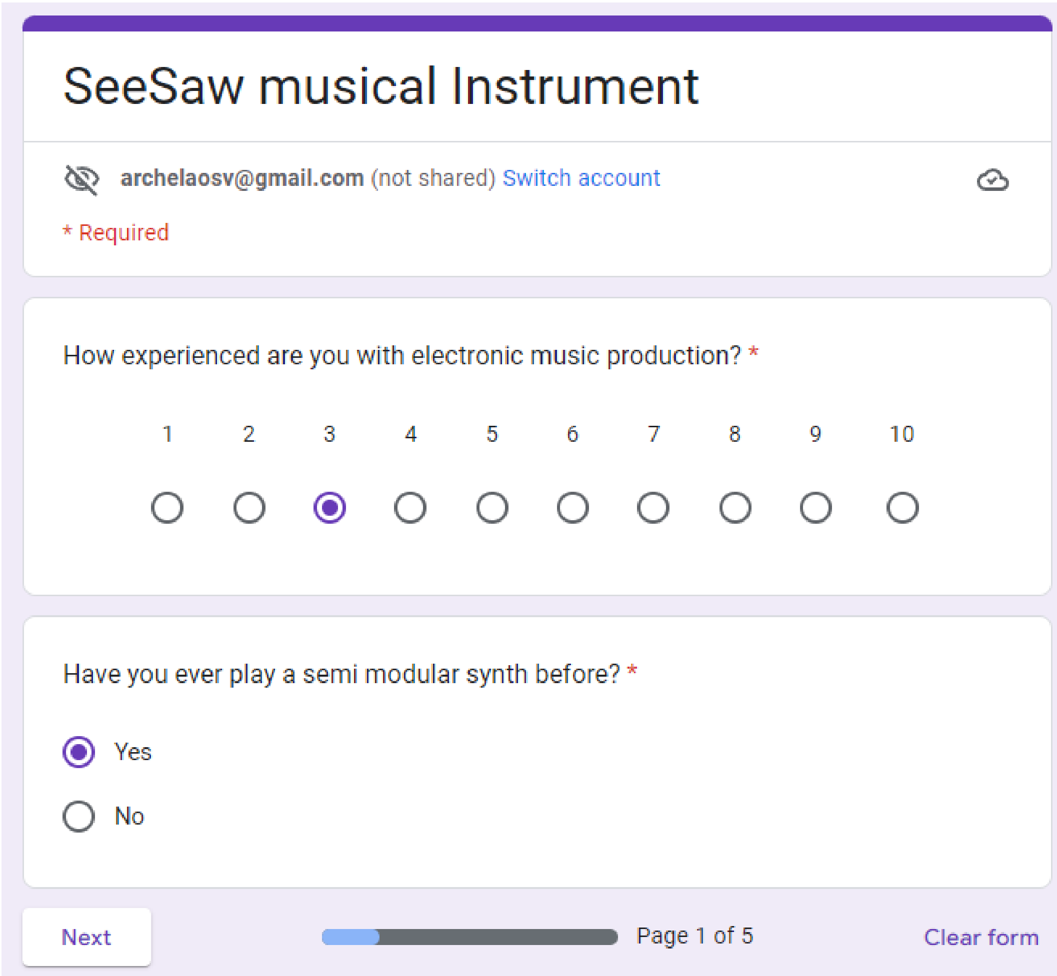
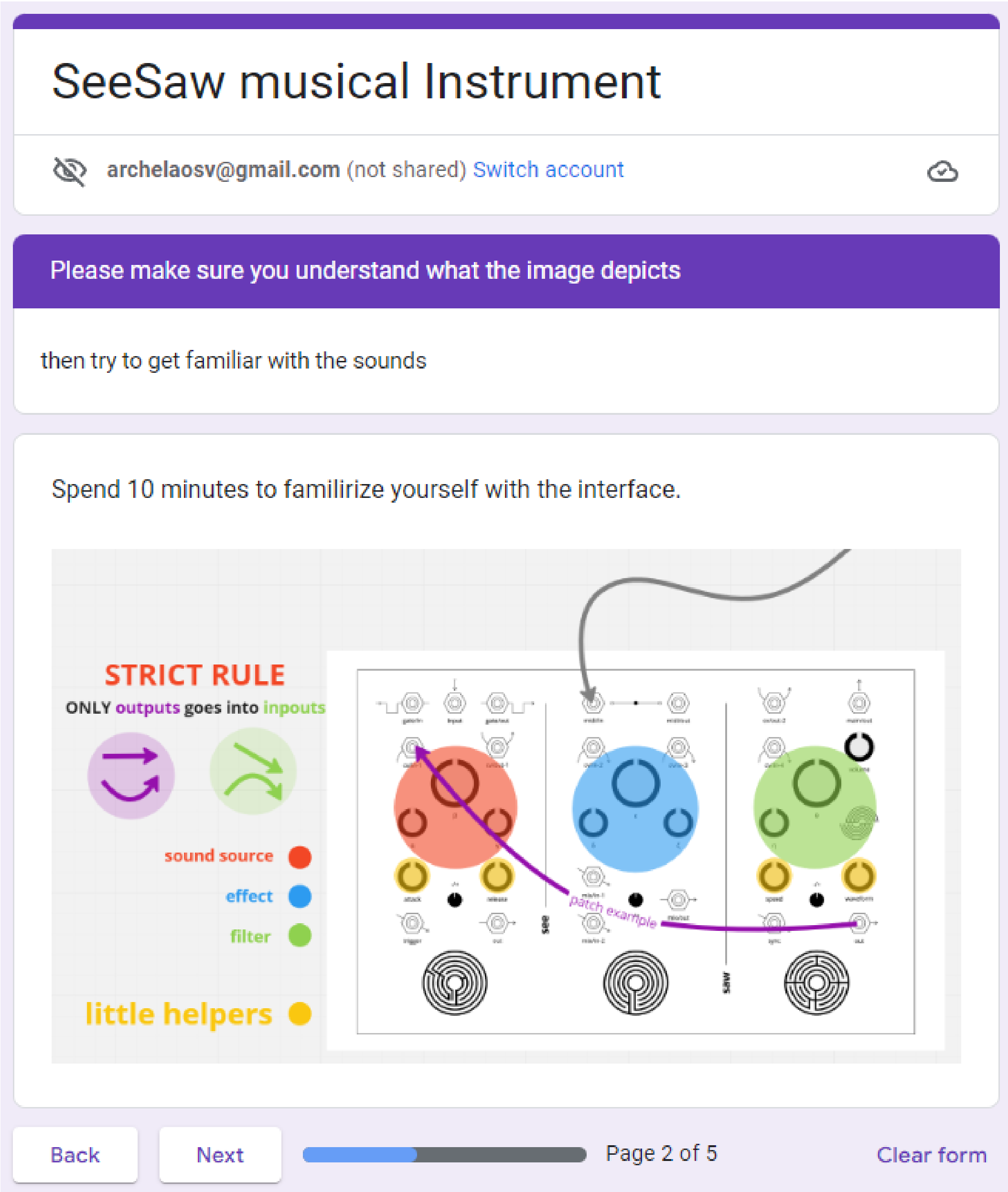


Figure A.6: Evaluation



SeeSaw musical Instrument

archelaosv@gmail.com (not shared) Switch account

Please make sure you understand what the image depicts

then try to get familiar with the sounds

Spend 10 minutes to familirize yourself with the interface.

Back

Next

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Clear form

Figure A.7: Evaluation

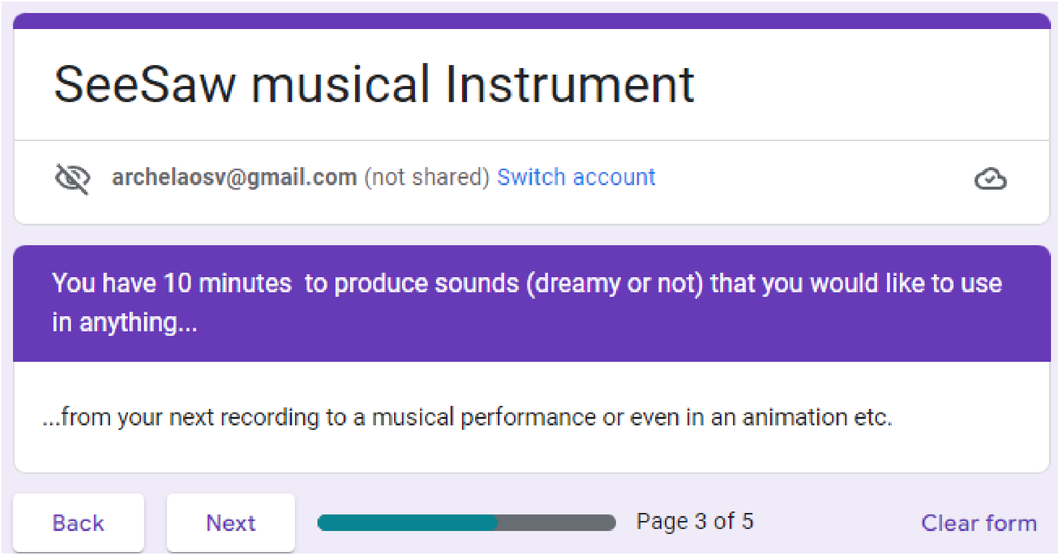

Figure A.8: Evaluation

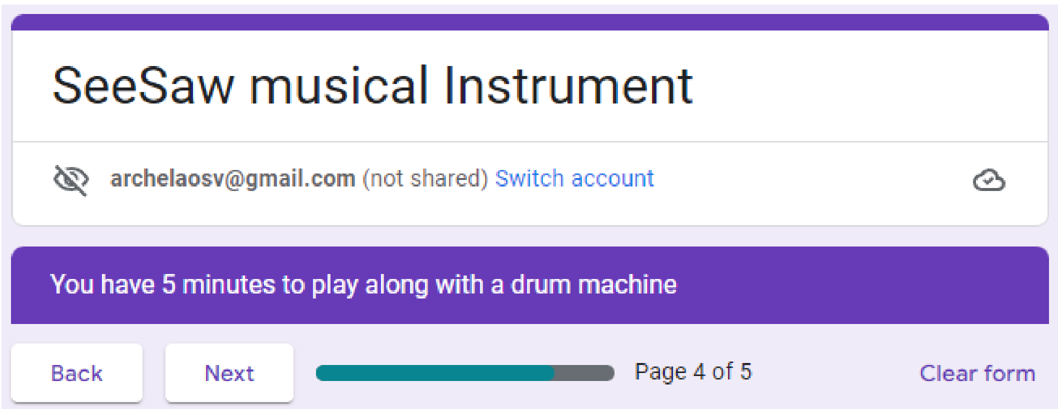

Figure A.9: Evaluation